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FLAT CONDUCTOR CABLE MANUFACTURE AND INSTALLATION TECHNIQUES

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ABSTRACT

The design and manufacture of flat conductor cables of various types are discussed in this report. Emphasis is given to cable termination techniques, interconnection hardware, cable harness manufacture, and installation methods. Also presented are the results of an extensive flat cable installation exercise in the Saturn S-IVB stage.

Current plans include design studies for Apollo applications systems and the development of cable and connector hardware for higher frequency, high power, and connector pin function change requirements.

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Wilhelm Angele

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ASTRIONICS LABORATORY
RESEARCH AND DEVELOPMENT OPERATIONS

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FLAT CONDUCTOR CABLE MANUFACTURE AND INSTALLATION TECHNIQUES

SUMMARY

The various types of flat conductor cables and their design and manufacture are discussed. Cable termination techniques, interconnection hardware, cable harness manufacture, and installation methods are described. The results of an extensive flat cable installation exercise in the Saturn S-IVB stage are presented.

Present plans are for design studies on the Apollo application systems. Also, further cable and connector hardware is being developed for higher frequency, high power, and connector pin function change requirements.

INTRODUCTION

The original flat conductor cable was a printed circuit type product made of very thin printed circuit material. It had 35 parallel conductors on about 1.25 mm (50 mil) center spacing. The termination of the 1 m (40 in.) long cable was made in the printed circuit style with eyelets for soldering to the pins of round wire connectors.

It soon became apparent that bulk cable in great length must be made available at a reasonable cost to compete with round wire prices. It was also recognized that a new inexpensive and reliable termination system compatible with the lightweight flat cable was required.

During the following years several flat cable designs and production methods were developed. Severe restrictions resulting from the limited availability of adequate adhesive systems, qualified dielectric films, and suitable flat copper conductors had to be overcome. The establishment of standards and specifications was another problem. Attempts to use metric dimensions for the cable standards at that time, the beginning of the new flat cable technology, had little support and met much resistance. The development of qualified supply sources for cables and connectors is still in process. The biggest task was, and still is, to educate the equipment designers in the application of the new cable system.

This paper does not include further details of chronological development but highlights the latest techniques of cable design, manufacturing, and installation and presents a comparative analysis of a typical flat cable and round wire application.

FLAT CABLE DESIGNS

Flat conductor cables can be grouped into three categories: regular cables (the unshielded, low power cables that constitute approximately 80 percent of flat cable applications), power cables, and shielded cables. Many of the standard dimensions of regular cables, e.g., overall width, conductor thickness and width, and conductor spacing, are applied throughout the three categories.

Regular Flat Cables

Some of the best plastic materials used in making flat cables are listed in Table I. Polyvinyl chloride (PVC) is added for comparison since it is used for round wire cabling.

TABLE I. PLASTIC MATERIALS

	Mylar	Kapton	Teflon(FEP)	Kel F	PVC
Tensile Strength N/m^2 (psi)	140×10^6 (20 000)	140×10^6 (20 000)	20×10^6 (3000)	30×10^6 (4500)	20×10^6 (3000)
Service Temp °K (°C) Max	423(150)	673(400)	473(200)	473(200)	358(85)
Service Temp °K(°C) Min	213(-60)	3(-270)	53(-220)	33(-240)	233(-40)
Dielectric Strength V/mm (V/mil)	280 000 (7000)	280 000 (7000)	112 000 (2800)	44 000 (1100)	32 000 (800)
Dielectric Constant 10^2 Hz	2.8	3.5	2.1	2.5	3
10^8 Hz	3.7				4
Volume Res Ω cm	10^{18}	10^{16}	2×10^{18}	3×10^{16}	10^{10}

The most widely used design is the symmetrically laminated form (1, Fig. 1). The conductors are sandwiched between plastic films.

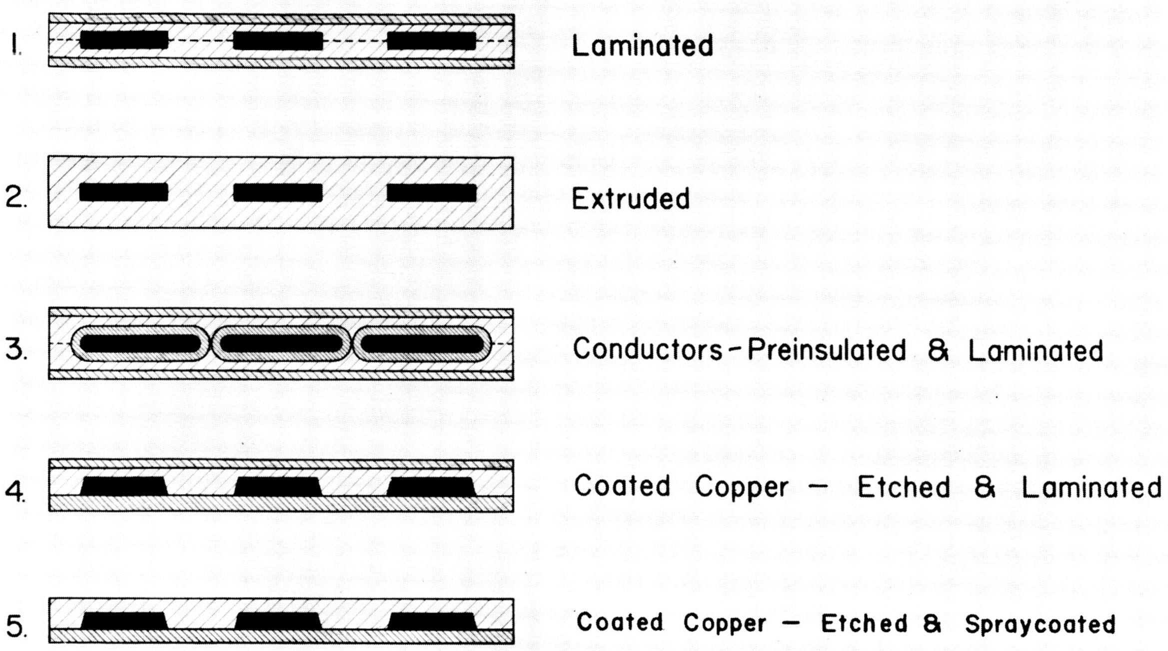


FIGURE 1. VARIOUS MANUFACTURED FLAT CONDUCTOR CABLES

An adhesive is used to keep the conductors properly spaced and to assure integrity of the cable configuration when exposed to the various operational conditions.

The extruded form (2, Fig. 1) is made with flat conductors of the same dimensions as those used in laminated cables. The insulating material is applied by the extrusion process.

Preinsulated and laminated cable (3, Fig. 1) is manufactured by the standard laminating process except that the conductors are first coated with insulating varnish. This allows the conductors to be laid parallel to and in proximity with one another.

Cables having etched conductors are shown in 3 and 4 of Figure 1. Such cables have generally better controlled center spacing and permit, therefore, a smaller gap between conductors.

Cables of the first two types described usually do not have less than 0.64 mm (25 mils) between conductors while etched conductor cables and the preinsulated conductor types allow gaps as small as 0.2 mm (8 mils). These narrow gap cables are called high density cables.

Table II provides data that have been adopted a͜ standard for flat conductor cables.

TABLE II. STANDARD DIMENSIONS FOR FLAT CONDUCTOR CABLES

Nominal Cable Width	mm 7 13 25 36 50 63 75 (in.) (0.25) (0.5) (1) (1.5) (2) (2.5) (3)
Conductor Spacing	mm 1.3 1.9 or multiples (in.) (0.050) (0.075) thereof
Conductor Thickness	mm 0.05 0.10 0.15 0.25 (in.) (0.002) (0.004) (0.006) (0.010)
Attainable Wire Sizes	AWG #5 and smaller gages
Operating Temperature	123 to 523°K (-150 to 250°C)

Combinations of these various parameters are used to produce cable having properties appropriate for most applications. NASA-MSFC has mostly used cables with 0.1 by 1 mm (4 by 40 mil) conductors on 1.9 mm (75 mil) center spacing for testing electrical properties and environmental qualification.

Power Cables

Power cables (Fig. 2) may have conductors of any desired width, preferably in multiples of the standard center spacing of 1.3 or 1.9 mm (50 or 75 mils) and as wide as the present maximum standard of 75 mm (3 in.). The thickness of copper is limited only by the cable flexibility requirement; 0.25 mm (10 mils) seems to be generally acceptable. It may be of interest that the standard receptacles of the MSFC type can be used with flat power cables without any changes, if the current does not exceed three amperes per contact spring. For example, a 50 mm (2 in.) power cable with two conductors uses 24 contact points per conductor. Current carrying capacity of such a termination is 75 amperes. For still more conductivity, two single conductor cables each 50 mm (2 in.) wide and 0.25 mm (0.010 in.) thick can be used and terminated with the 50 mm (2 in.) standard plug.

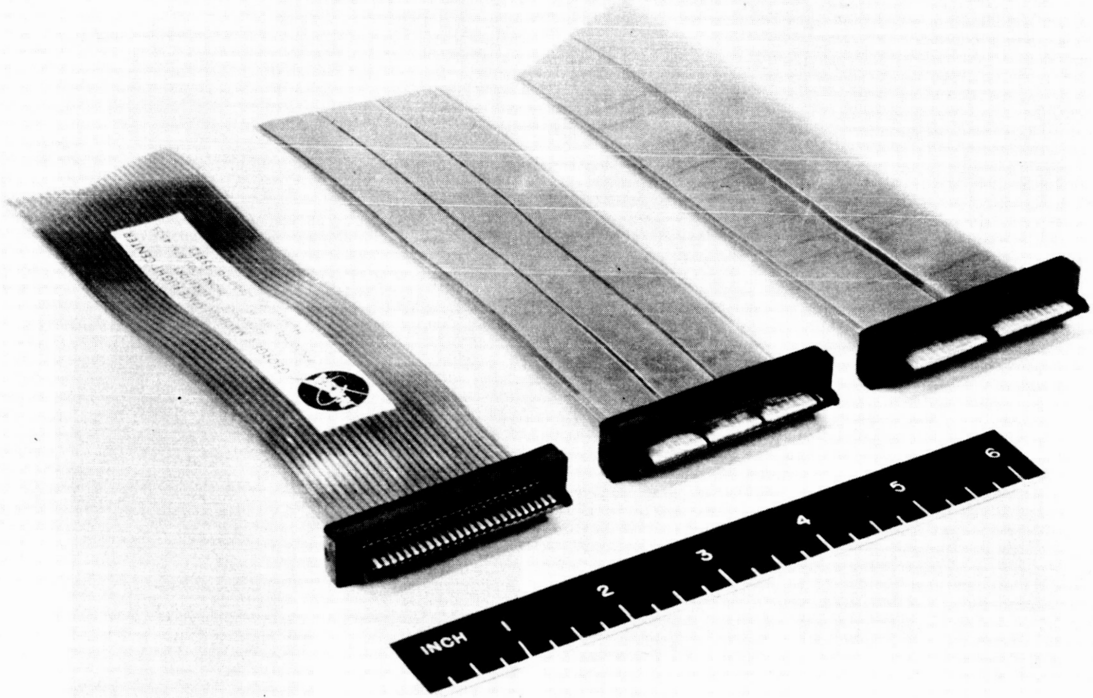


FIGURE 2. POWER CABLES COMPARED WITH REGULAR CABLE

The power cable is a very useful by-product of the flat conductor cable development, which was originally intended for signal or low power use only. Cables with heavier than 0.25-mm (10-mil) thick conductors will need special connectors and can only be used where frequent bending is not required.

Shielded Cables

The simplest type of shielding, often applied in computer technology, is accomplished by the use of common flat cable with small conductors and by connecting every second conductor to ground. This mode is very effective for isolation.

Cover layers of thin metal foil, laminated as additional layers by the same process used in making standard laminated cable, generally give sufficient shielding protection, as has been shown by experience. Yet, foils even 0.013 mm (0.5 mil) thick cause considerable loss of flexibility and often develop

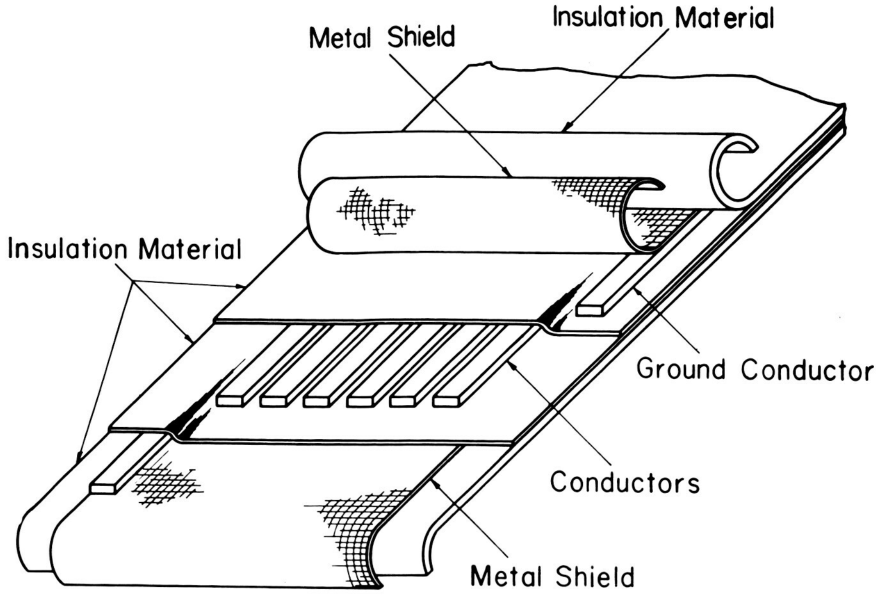


FIGURE 3. DIAGRAM OF SHIELDED FLAT CABLE

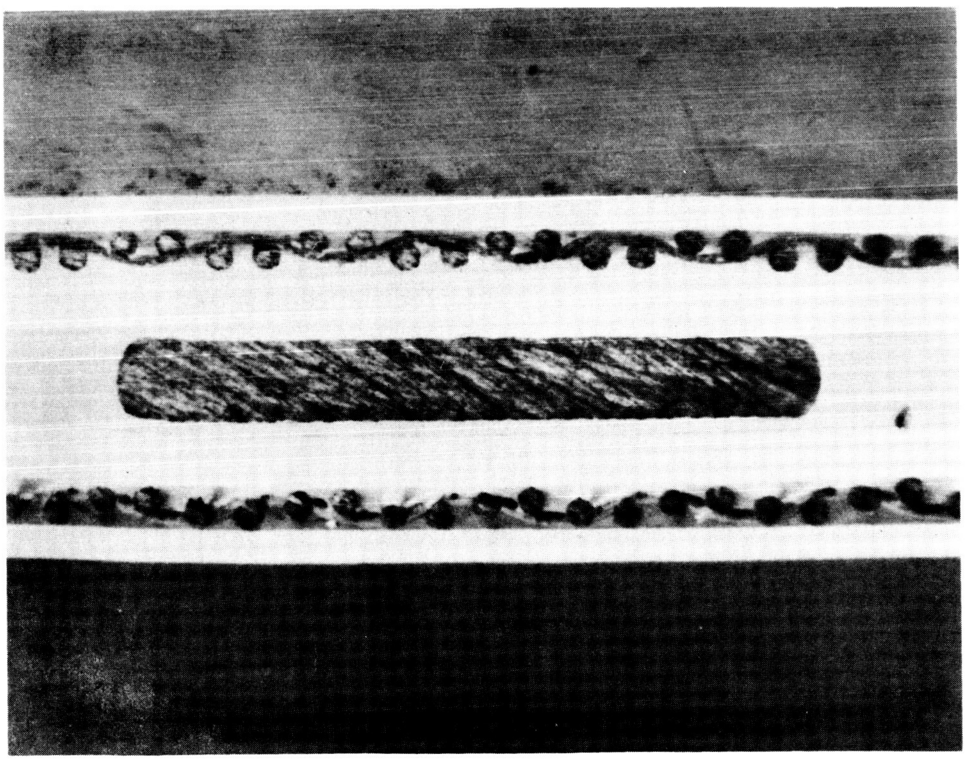


FIGURE 4. MAGNIFIED CROSS SECTION OF SHIELDED CABLE

wrinkles and fractures of the shield when flexed. Vapor deposited metal shields with high ductility have been reported as useful. Cables laminated with shields (Figs. 3 and 4) made of fine mesh screens demonstrate very good shielding properties. The woven screen made of 0.026 mm (1 mil) bronze wires in twill weave seems to produce the needed flexibility. The total cable thickness shielded by a screen at each side is about 0.4 mm (16 mils). This includes 0.1 mm (4 mils) copper conductors and four layers of Kapton insulation plus adhesives.

Another effective design mainly used to minimize the effects of strong electromagnetic interference is that of quasi-twisted conductors. Figure 5 shows a cable with 12 pairs of twisted conductors. The zigzag pattern of the conductors is printed and etched on both sides of a flexible copper-plastic-copper laminate. This pattern effectively resembles twisted wires.

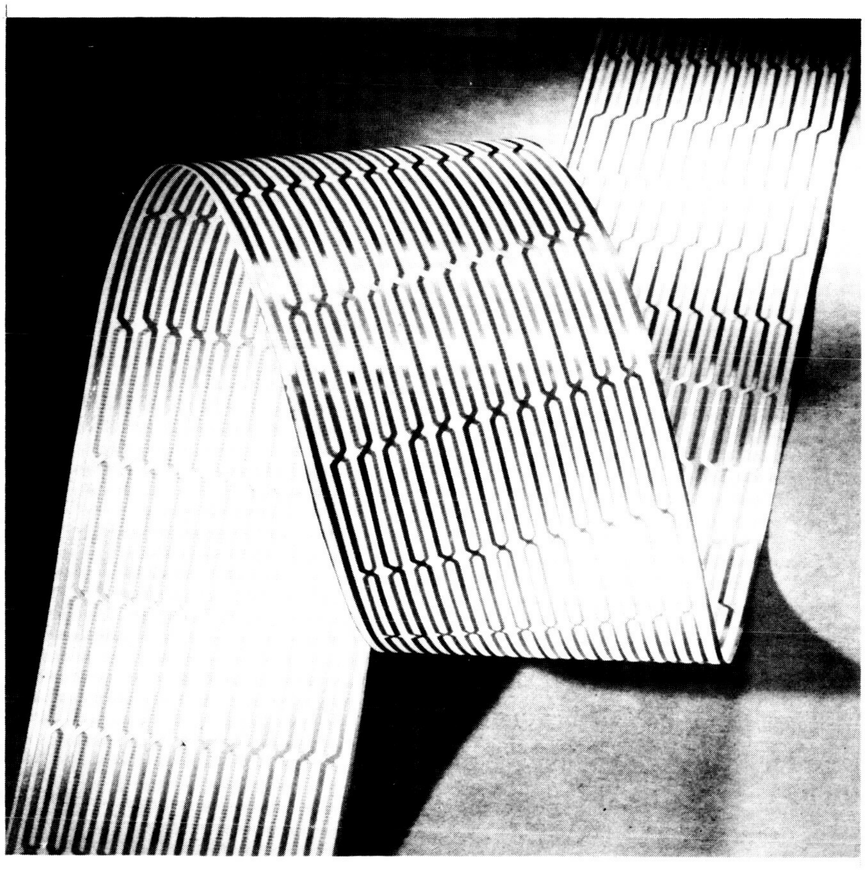


FIGURE 5. QUASI-TWISTED CONDUCTORS FOR SHIELDING EFFECT

Another very efficient shielding is accomplished by the double-layer cable. Two identical cables are sewed together along their margins. This arrangement makes the conductor pairs largely immune to strong electromagnetic ac fields. The mechanical flexibility is high as compared to standard shielded cables using fine screens.

The development of shielded cables and the establishment of good performance specifications, electrical data, and standards are still in the beginning stages; however, very good shielded cables have been produced and much useful data have been gained.

Materials and Methods

Numerous methods and materials may be used to make good cables. Teflon extruded cables have proven to be of very excellent electrical quality. For commercial applications, silicone rubber and polyvinyl chloride have been used successfully. In some cases of very high temperature applications, glass-fiber reinforced plastic films are preferred. Until recently, high temperature cables made of polyimide material could only be laminated with Teflon FEP as an adhesive. Teflon is a very desirable dielectric material, but its thermal properties limit the exposure of the cable to 473°K (200°C). Improved cables have been made by polyimide coating one side of copper tapes 300 mm (12 in.) or more in width, printing and etching the desired conductor pattern, and covering the etched side with a polyimide film using Teflon FEP (4, Fig. 1). This type of cable can stand up to 523°K (250°C) working temperature because of the strong bond between the conductors and the basic polyimide background. FEP, being a very good dielectric which bonds well to polyimide, requires only a 0.2 mm (8 mils) insulating space between the conductors to withstand 2500 volts ac in testing. A still higher temperature cable became possible with the development of a high temperature polyimide adhesive which is used to cement the Kapton (polyimide) film to the etched surface of the copper-polyimide laminate. The temperature limits for this cable have not been established yet. Termination plugs and interconnection hardware to match the high temperature range of pure polyimide cables need to be developed.

Still another family of flat conductor cables is the woven type. Weaving is an economical way because looms of large width for making many cables simultaneously are available. Also, weaving can be fully automated and is very inexpensive. The weaving operation produces precise center spacing of the conductors and a woven cable will not delaminate at high temperature vacuum. Flat conductor cables can be woven with glass fiber for high mechanical and high temperature strength. The conductors can be polyimide insulated before weaving to give protection and to maintain flexibility.

Woven flat cables have been studied to some extent by the U. S. Army Electronics Center, Fort Monmouth, New Jersey.

MANUFACTURE OF FLAT CONDUCTOR CABLE

Numerous methods of manufacturing flat cable have been developed with varying degrees of success. The techniques, or combination of techniques, that have been applied include laminating, etching, printing with conductive materials, weaving, punching, galvanic deposition, molding, extrusion, and vacuum deposition. Laminating and etching are the most accepted and widely used methods. Etching is used mainly for flexible circuitry. Laminating machines were built by several companies applying various methods. Different approaches and designs have been used to accomplish precise conductor spacing, which has been a major problem. The following paragraphs describe the laminating method and related equipment.

Conductor Preparation

The prerequisite for achieving consistently accurate center spacing is the use of straight and flat conductors. Even slight deformations invariably cause irregularities in center to center spacing; that is, flat wires are often wound on a standard spool in the typical helical fashion. At the end of the layer at the flange of the coil form, the helix has to be reversed to continue in the next layer. This reversal deforms the flat wire permanently and, if not straightened, causes spacing errors in the flat cable. Additional deformations occur when the pitch of winding is not accurately adjusted to the width of the flat wire.

Mr. Saums, formerly with Anaconda Wire & Cable Company and a foremost authority on wire treatment and coating, has advised annealing, cleaning, and straightening the flat conductors in a unique way before using them to make flat cabling.

A wire conditioner (Fig. 6) was built according to Mr. Saums' proposal to accomplish these three functions. The flat wire, forming a closed loop as the secondary side of a transformer, is guided through distilled water. The

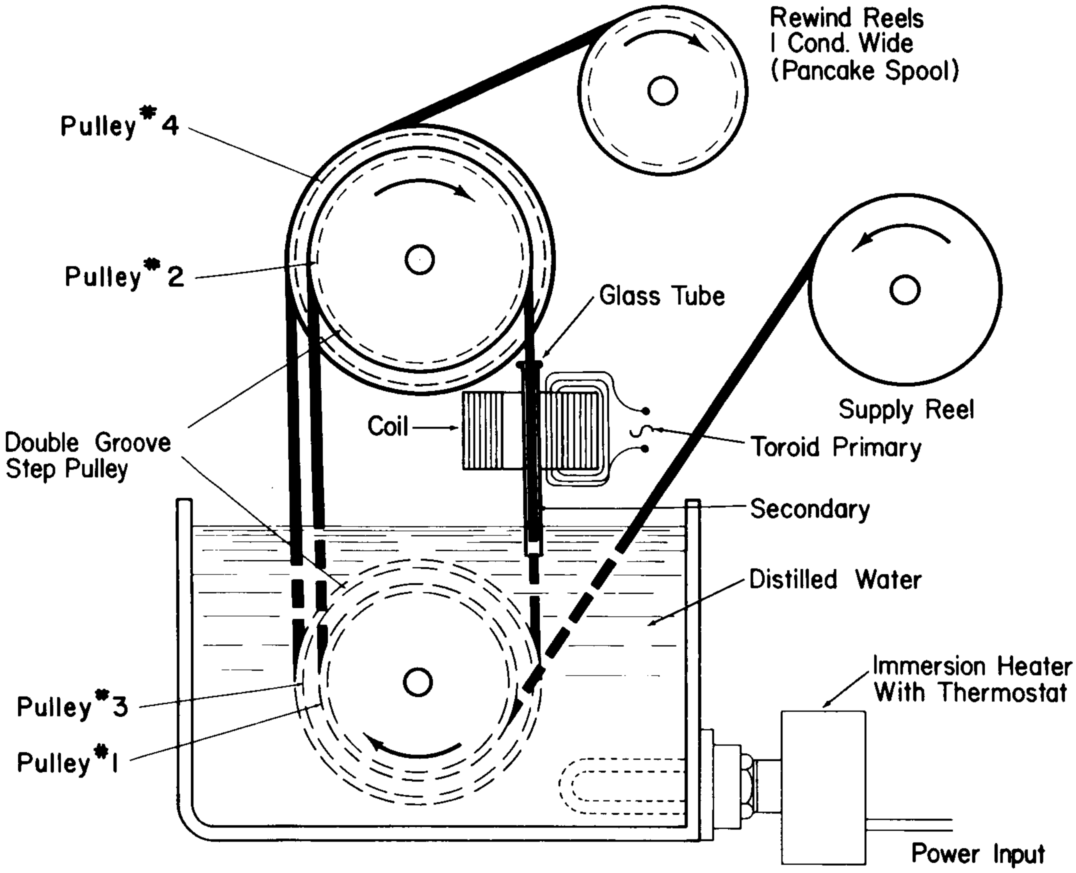


FIGURE 6. WIRE CONDITIONER

water is temperature controlled by a thermostat and immersion heater to assure uniform performance. As the flat wire, heated by the secondary current of the transformer, enters the water, steam is developed and this mechanically performs the cleaning. At the same time, quenching and annealing takes place. The wire passes over four grooved pulleys; two are below the water level and two are above. Pulleys 3 and 4 have one percent more diameter than pulleys 1 and 2, causing the wire to be stretched by one percent. This stretching caused the straightening. To prevent new deformations and defects, the wire is then wound to pancake spools, having the width of one flat wire only. These types of flat spools are also used as dispensers for the cable laminator.

Laminators

Several laminators were built by various companies with different basic approaches and configurations. Accomplishing precise conductor spacings has been a major problem. Different designs for hot nip rollers have been used, ranging from steam and hot oil to electricity as a heat source. The next important problem was, and still is, the need for pressure pads for the lamination roller surfaces with good heat conductivity for fast heat transfer. Minor problems are controllable tension and guiding devices for conductors, tapes, and the cable; temperature; pressure; speed control; and others. Some of the machines went through many changes to incorporate new developments and to handle new requirements. The existing machines had been designed by companies which needed such laminators for their own flat cable production. No standard laminator was on the market.

To promote the art of laminating flat conductor cables of various types and dimensions, NASA-MSFC placed a contract with the G. T. Schjeldahl Company, Northfield, Minnesota, to design and build a laminator. The specifications incorporated most of the information collected during the years of contact with cable laminating companies, though most did not show their machines to the cable buyer. It was believed that a more universal and better laminator could be built utilizing experience and know-how of individuals interested in promoting flat cable technology. The request called for a laminator capable of producing cables up to 150 mm (6 in.) wide, using a large number of conductors of various sizes and handling all practical and useful dielectric films including Mylar, Teflon, and Kapton and the corresponding adhesives. The machine (Fig. 7), including the wire unwind frame for 42 spools as built by Schjeldahl to MSFC specifications, is 4500 mm (15 ft) long, 900 mm (3 ft) wide, and 2000 mm (6.5 ft) high. The conductor spool shafts have adjustable friction clutches for tension control. The laminating cylinders, 200 mm (8 in.) in diameter and 200 mm (8 in.) wide, are electrically heated with stationary heating elements, and the temperature can be automatically controlled to a few degrees within a wide range. The lamination pressure is produced by air cylinders and is adjustable well over the needed limits. If the type of adhesive permits, the machine can laminate cables with speed up to 9 m (30 ft) per minute. The laminator is designed as an experimental machine rather than for high production speed. For laminating Kapton films with polyimide adhesives, lower speeds of 300 to 900 mm (1 to 3 ft) per minute will be used. And, even at that low speed, the cable is assembled only by initial tack. The cable needs to be post-cured for eight hours to complete sufficient polymerization of the adhesive. For simplicity of design, only the nip rollers and draw rollers are motor driven. All other rollers are idlers, including the edge trim cutters.

The plastic tapes are guided by automatic measuring and control systems. A photo-optic edge sensor controls the tape adjustment to the desired position by use of a servo system. Tape tension control is also provided for the unwind and rewind rollers.

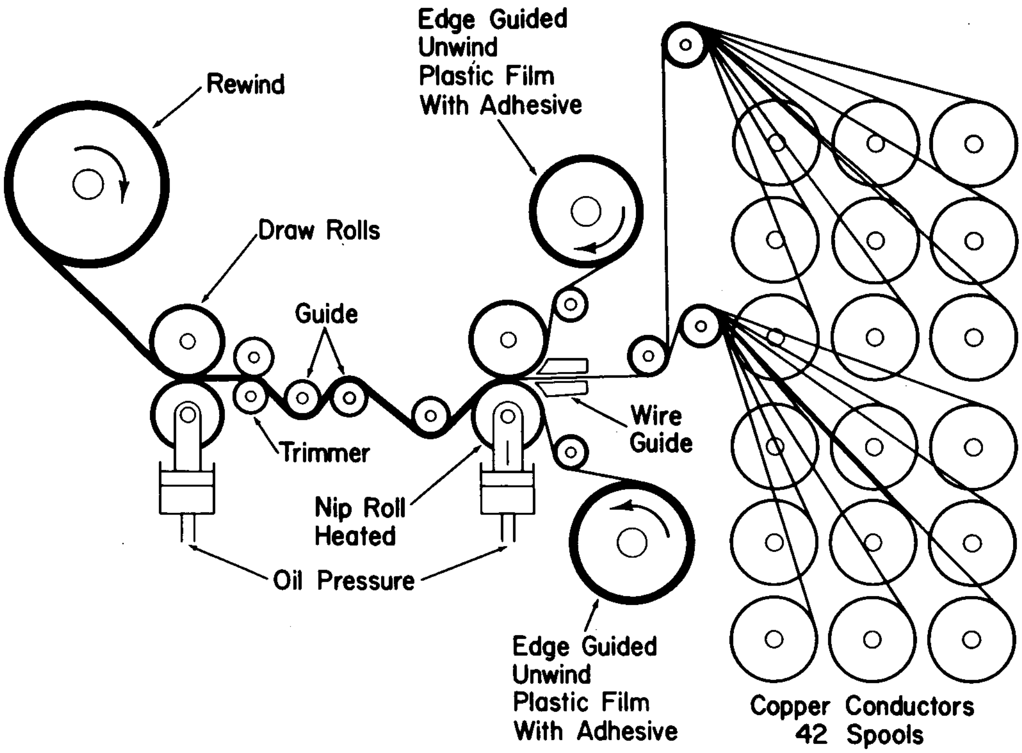


FIGURE 7. SCHEMATIC OF FLAT CABLE LAMINATOR

The conductor spacing device is located close to the nip rollers. Different approaches are used, depending on the type of adhesive used for laminating. One approach has the conductor guide extremely close to the contact line of the two laminating cylinders to eliminate possible deflection of conductors which have passed the wire spacers but have not entered the nip roll contact line. Another system used by Schjeldahl leads the conductors under great tension to one nip roll surface 90 degrees before the second roller adds the cover coat to the cable. This is supposed to let the conductors sink into the adhesive before the pressure of the second roller causes them to shift out of line.

The various types of wire guides deserve mentioning. Considering the temperature expansions of plastics and the high laminating temperature, the narrowing effect of the cable tension, and other cable width-changing influences, an adjustable conductor spacer seems unavoidable. This can be accomplished by using a comb which can be swiveled in the plane of the wire harp. The spacing changes as the swivel comb rotates a few degrees. This swivel approach would be very useful if it would not exclude the proximity of the guide to the nip rollers. Another adjustable device was built and form-fitted to the nip rollers. The adjustability was sufficiently uniform; however, the rigidity left room for improvement. After all these efforts, the question arises; Is the shrinkage during one lamination process of a specific material not constant enough to use a fixed spacer which can be placed close to the nip line of the rollers?

Spacers with fixed distances can be made inexpensively and one can afford to have several available to suit the shrinkage of various plastic materials. A tapered block with guide grooves precisely machined to dimensions determined through experience may be the least expensive solution.

Laminating Procedure

The problems of actual laminating are manyfold. For reasons not quite understood, two hard rollers do not produce acceptable cables. If one roller has a soft surface (silicone rubber), a good bond can be produced but the cable curls and is not acceptable. A more symmetrical cable can be produced by having both surfaces resilient. For the laminating rollers, a resilient cover that could stand high temperature for a long time has not been found. Schjeldahl's laminator (Figs. 8 and 9) uses 1.3 mm (50 mils) blotting papers in roll form to avoid frequent repairs of the coated rollers. The blotting papers can be used several times after reconditioning.

The real problem in laminating is to squeeze adhesive into the empty spaces between the conductors without entrapping air bubbles. In laminating power cables of 0.15 to 0.2 mm (6 to 8 mils) conductor thickness, an inlay of dielectric material to fill the gap between the conductor edges may be needed, depending on the type of adhesive used. After the cable is laminated, the edges need to be trimmed to achieve the proper margin and cable width. An optical device is used to sense the outer edge of conductor number one to control the position of the cable before it enters the edge cutter.

When laminating shielded cable, the shielding materials need to be insulated from the ground and, therefore, must be two margins smaller than the actual width of the cable. The shielding material is used in the final widths properly guided and laminated to the prefabricated non-shielded cable. As previously mentioned, thermal expansion, laminating force, and cable tension change conductor spacing to a degree that necessitates measuring and space

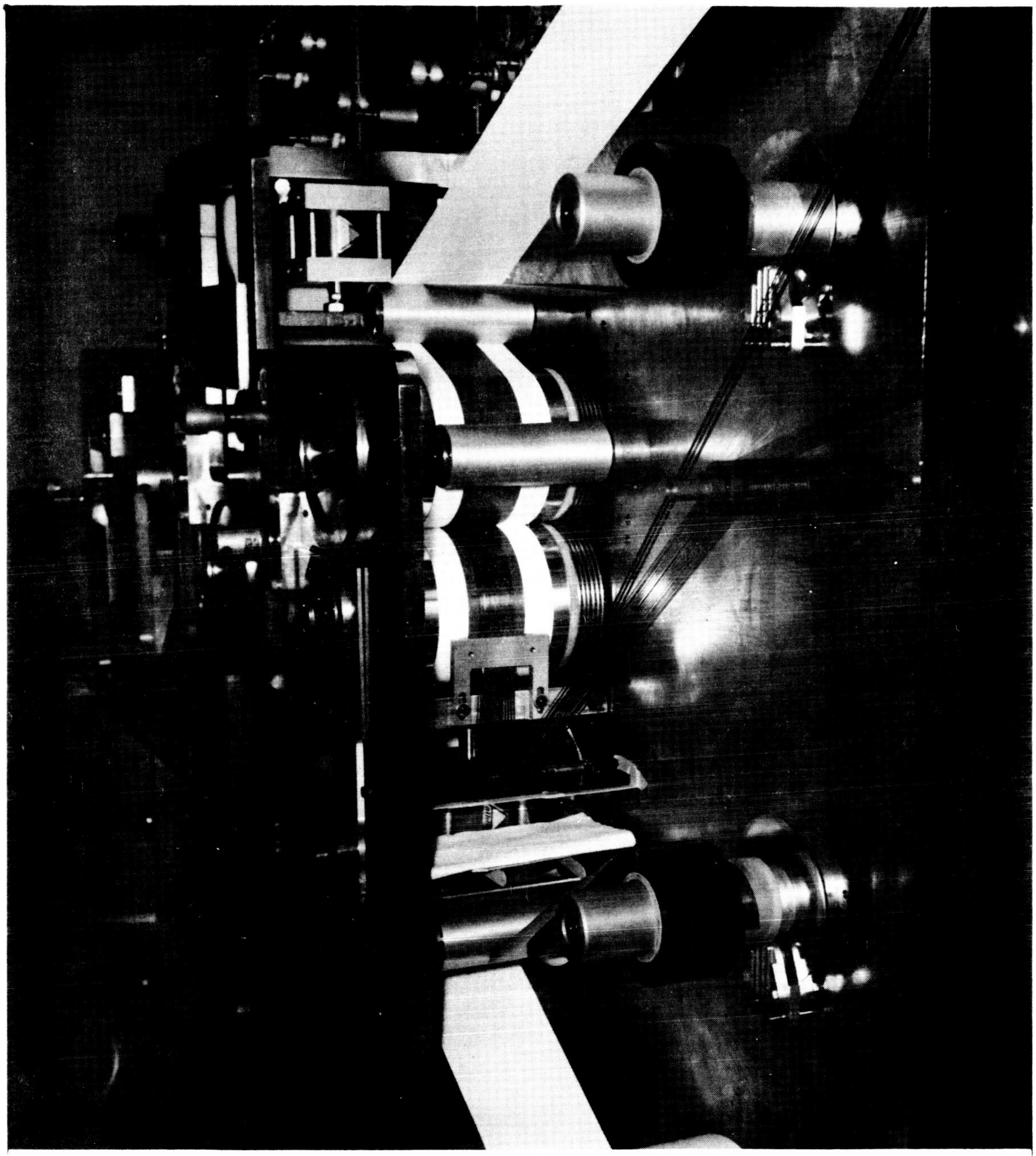


FIGURE 8. VIEW OF SCHJELDAHL LAMINATOR SHOWING LAMINATING PROCESS

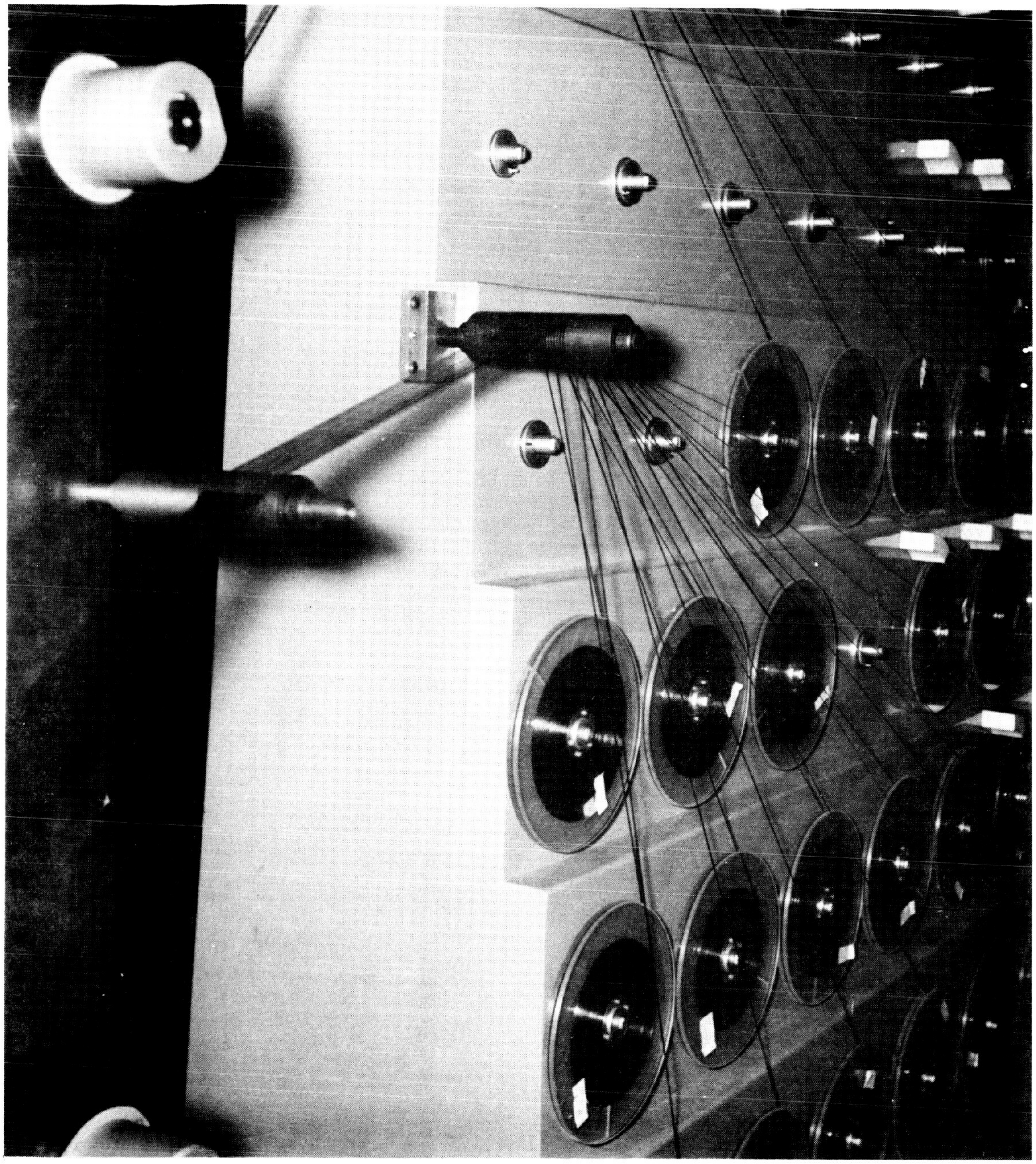


FIGURE 9. VIEW OF SCHJELDAHL LAMINATOR SHOWING COPPER CONDUCTOR SPOOLS

correction. Measuring of center spacing of the conductors is performed during the cable laminating process at some distance after the cable leaves the laminating rollers, cools off sufficiently, and shrinks to the final width. The cable runs over a photographic glass plate having the negative image of the cable dimensions and spacings including maximum allowable tolerances. A collimated light source under the photo plate will not be visible through the plate and cable if variations in center spacing, larger than permissible, do not occur. This relatively small measuring device is a "go/no-go" gage and shows irregularities as well as cumulative errors at one glance. It may be practical to install optical sensors which in turn control an adjustable wire guiding device. It is hoped that center space accuracies of ±0.05 mm/0.025 m(±2 mils/in.) cable widths can be accomplished without automatic conductor spacing control.

It is intended that, by using this cable laminating machine, detailed procedures for making cable with various materials of shielded and non-shielded types will be developed.

Very recently a new type of flat cable laminator (Fig. 10) has been advertised. The Fullerton Machinery Company in California has designed,

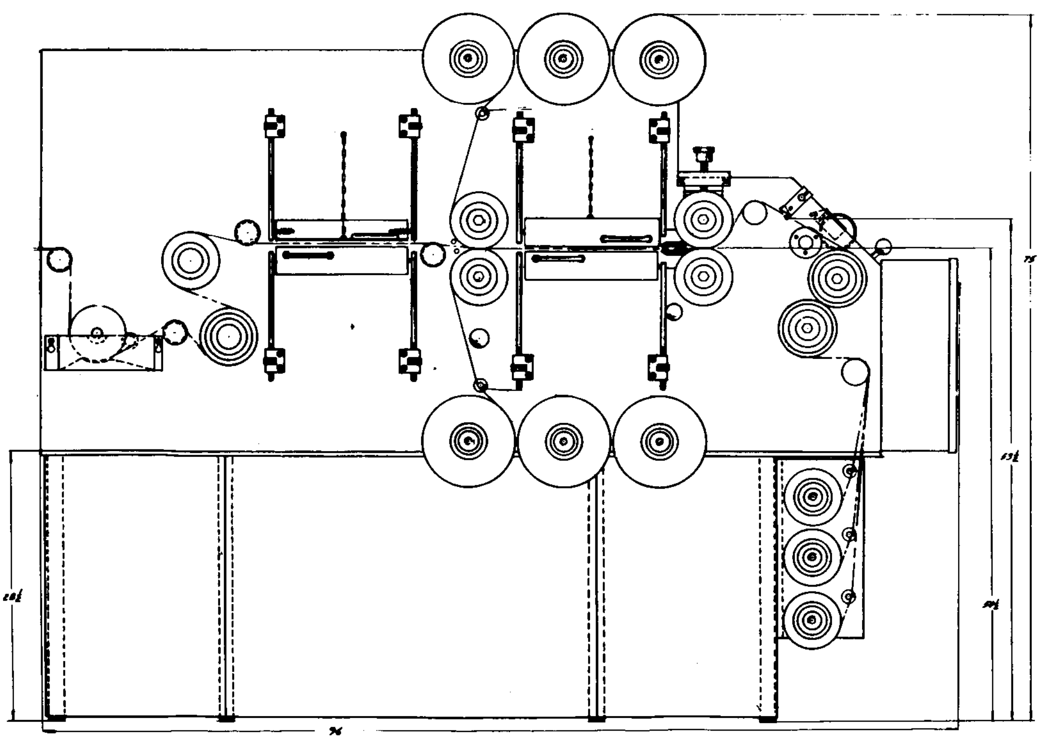


FIGURE 10. FULLERTON FLAT CABLE LAMINATOR - MODEL NO. 1330

manufactured, and tested a machine to laminate cables up to 200 mm (8 in.) wide at a speed of 3 m (10 ft) per minute. The Fullerton model 1330 operates on a heat-press-freeze cycle. This laminator has no hot rolls. It operates on the principle of rapidly quenching a preheated lamination sandwich in a chill-roll nip. Dimensional precision and stability are achieved by grooving the surfaces of the chill-rolls. The integrity of web bond and conductor encapsulation are guaranteed by micrometer adjustment of a fixed gap between the chill-roll surfaces. Process temperatures well in excess of 823°K (550°C) are achieved without the use of temperature deteriorating materials. This information was taken from the Fullerton specification sheet; however, a report will be published by the Fullerton Machinery Company at a later date.

CABLE TERMINATIONS

The most important factor controlling the reliability of any cable system is the cable termination and interconnection. Several approaches for flat conductor cables have been investigated by industry and government. The standard approach in round cable harness manufacturing is the use of pin and bushing, which are added to the end of the conductor by soldering, crimping, or welding. This approach is also possible in a modified way for the flat conductor cable system. Another approach uses connecting elements which are attached to the cable by piercing through the insulation material. A third basic approach, shown in Figure 11, is to strip the cable of its insulation and use the bare conductor surface, after proper protection against corrosion, to make contact with a contact spring of a connector receptacle. This third and last approach has been developed by MSFC, and tooling has been built for production use. It is also felt that higher reliability can be accomplished by reducing the number of junctions and reducing the number of contacting elements. A short description of the terminating process used by MSFC is given in the following paragraphs.

Cable Stripping Methods and Tools

Thermoplastic insulating materials such as Mylar can be stripped with a hot stripping tool (Figs. 12 and 13). The cable is simply inserted into the cable stripper; a heated blade bears down to the cable while the cable is pulled from under the blade. The insulation is sufficiently softened, or melted by the heat, to be scraped from the cable conductors. A fine film of plastic remains at the surface of the conductors and must be removed chemically before nickel and gold plating can be accomplished. The plating is done for the purpose of corrosion protection, improvement of surface conductivity, and wear resistance.

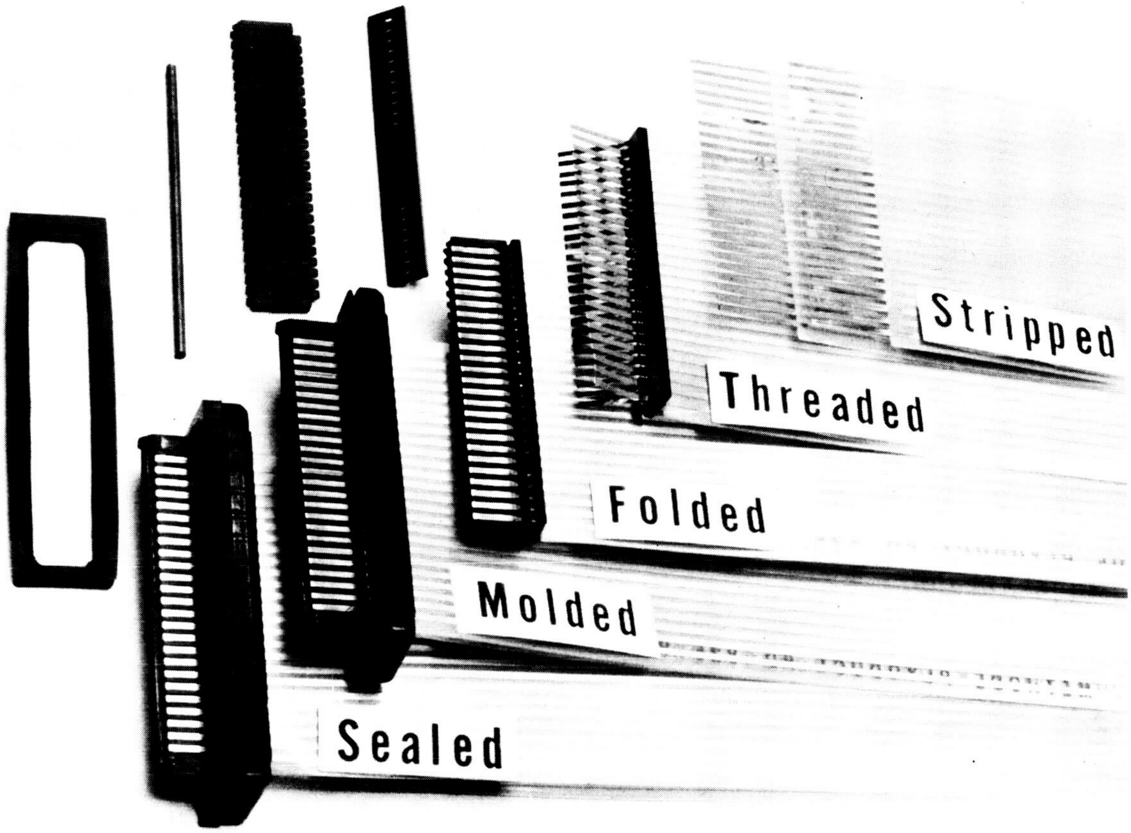


FIGURE 11. MOLDED PLUG ASSEMBLY SEQUENCE

Cables with FEP bonded Kapton films can be stripped easily and quickly with a sharp blade stripper without applying heat (Figs. 14 and 15). The blade is adjusted in the stripping tool to cut only through the Kapton film and not touch the surface of the conductors; the cutter blade adjusting tolerance is the thickness of the FEP adhesive. Chemical cleaning is not needed except for routine pickling before electroplating.

The third system, chemical stripping, can also be used. It reduces tooling costs considerably, but does not handle Teflon or Teflon bonded H-film insulation efficiently. The chemical stripping, using a commercial stripper with phosphoric acid as its major component, must be applied at about 373° K (100° C) and should be handled with care. This operation does not fit well into a harnessmaking area but can be handled satisfactorily in the electroplating shop.

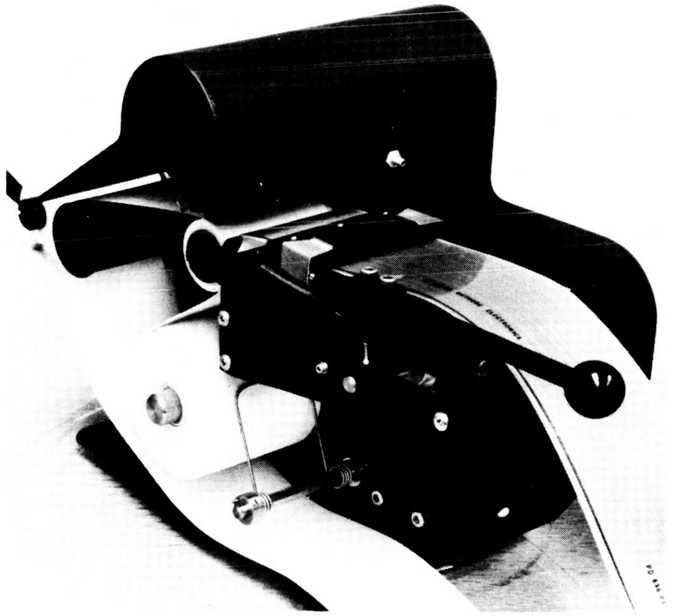


FIGURE 12. HOT STRIPPER

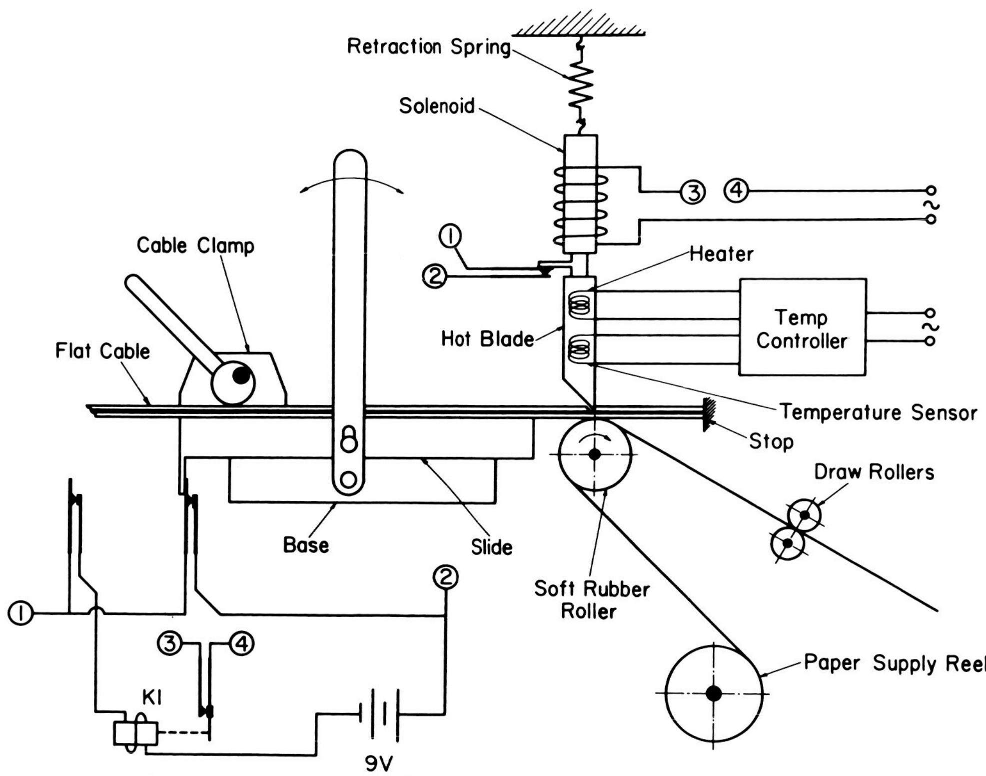


FIGURE 13. SCHEMATIC OF HOT STRIPPER

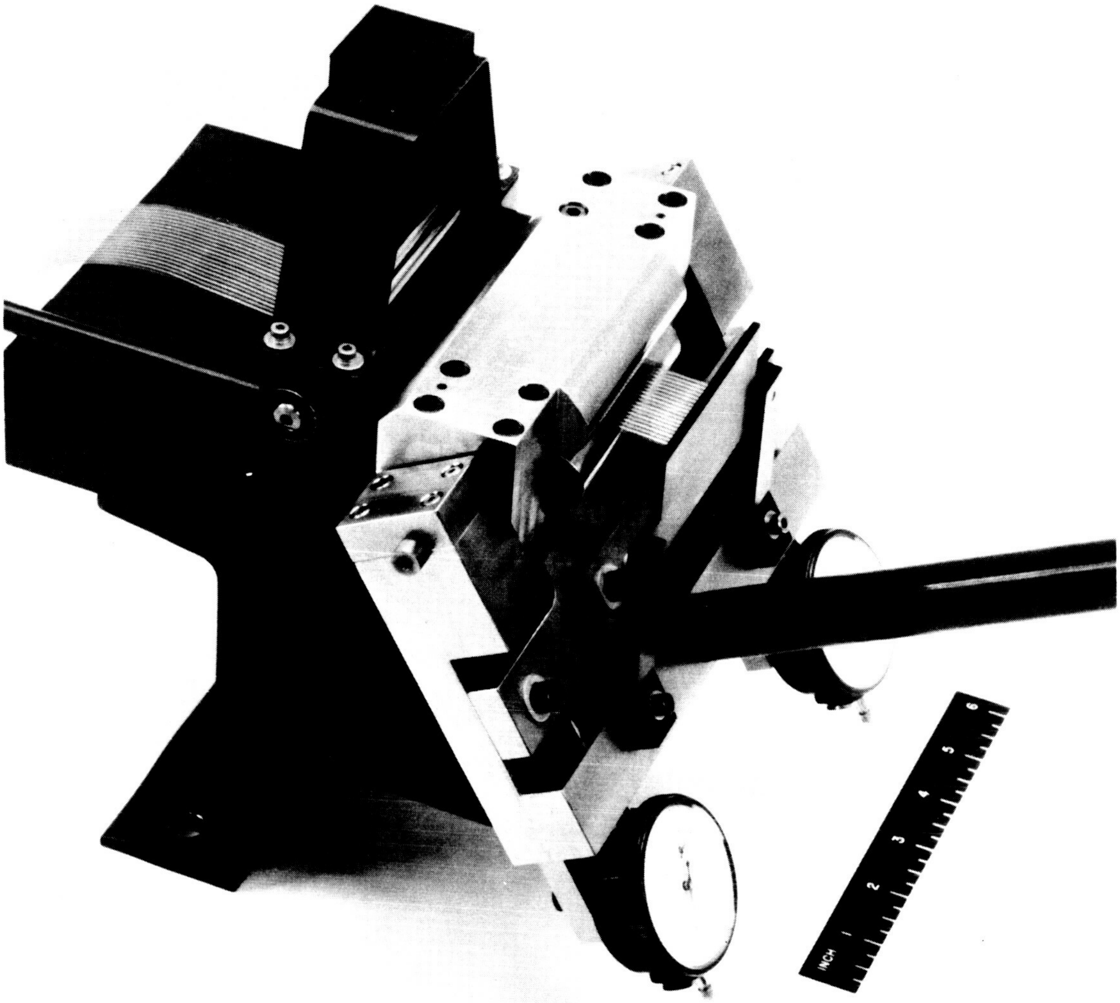


FIGURE 14. COLD STRIPPER

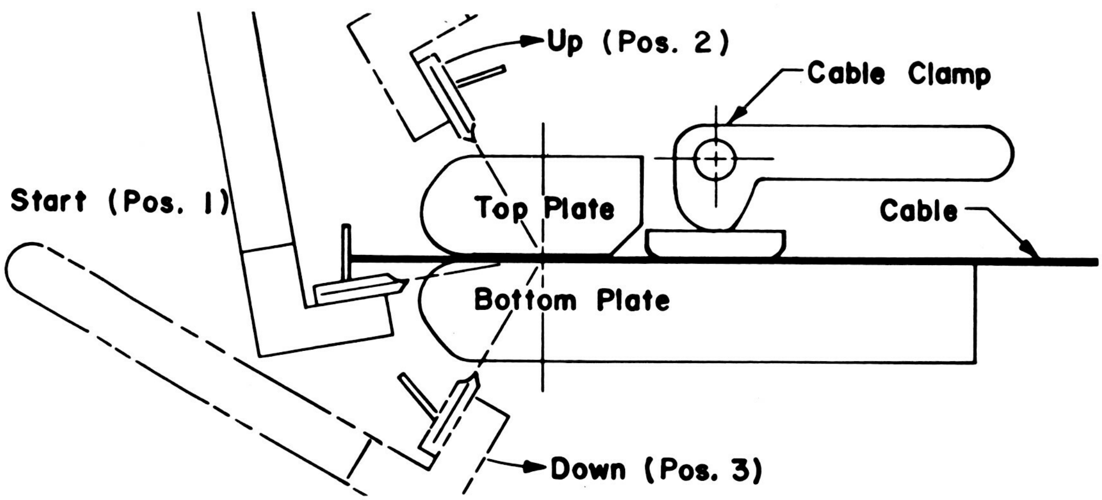


FIGURE 15. SCHEMATIC OF COLD STRIPPER

Plug Assembly and Molding

After the cable ends have been cleaned and electroplated, the bare conductors are laid into premolded plastic spacers using seating and folding tools. The precisely molded spacer can correct, to some degree, spacing errors in the flat cable (Figs. 16 through 19). The cable terminated thus far is intended for use inside of black boxes. The major use of flat cables will be for interconnecting of black boxes. For this purpose a heavy flange bearing a face seal and a strain relief is fabricated onto the cable by means of a subsequent molding operation.

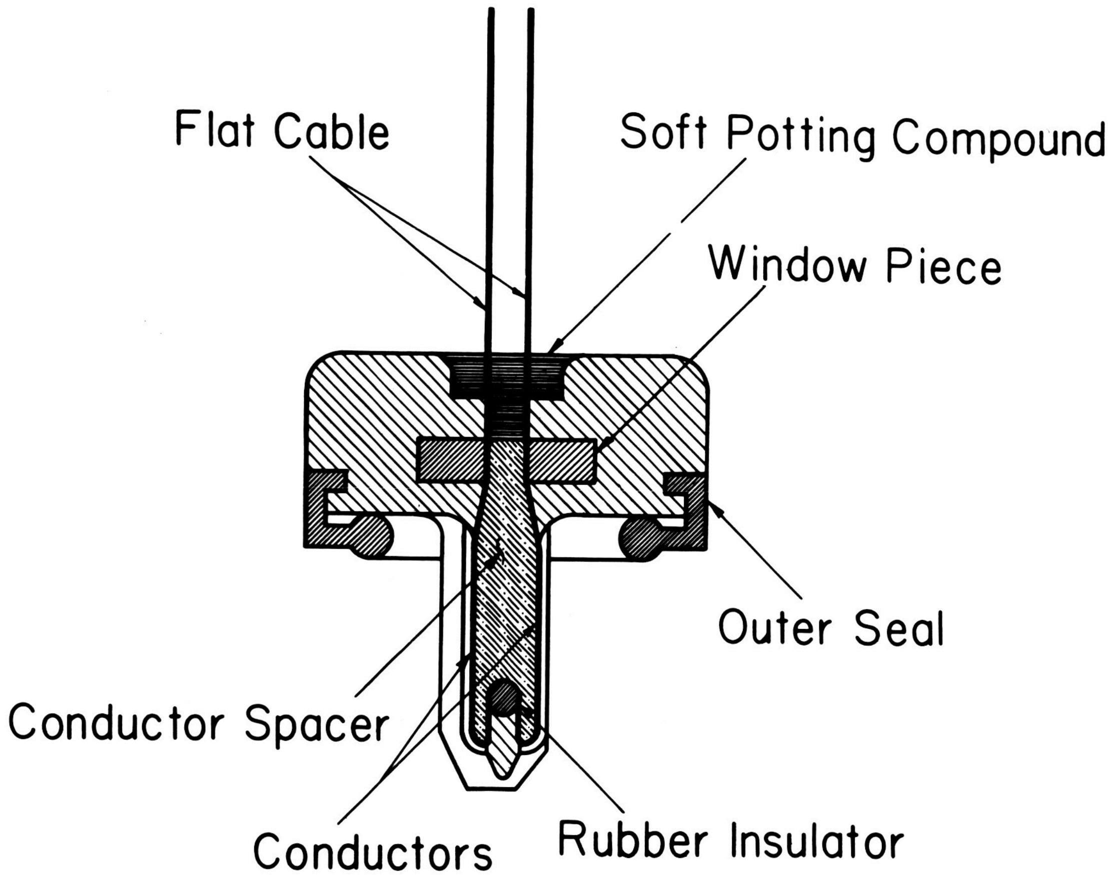


FIGURE 16. PLUG FOR SINGLE OR TWIN FLAT CONDUCTOR CABLE

The time needed for stripping, folding, and molding of a cable termination, not including electroplating, takes less than three minutes. This lightweight cable termination is very inexpensive and is highly reliable, having no added metal parts and no junctions. For example, a termination having two 50 mm (2 in.) cables with 25 conductors each weighs only 8 grams. This is extremely light and inexpensive as compared with even the latest connector plug of the round wire cable system.

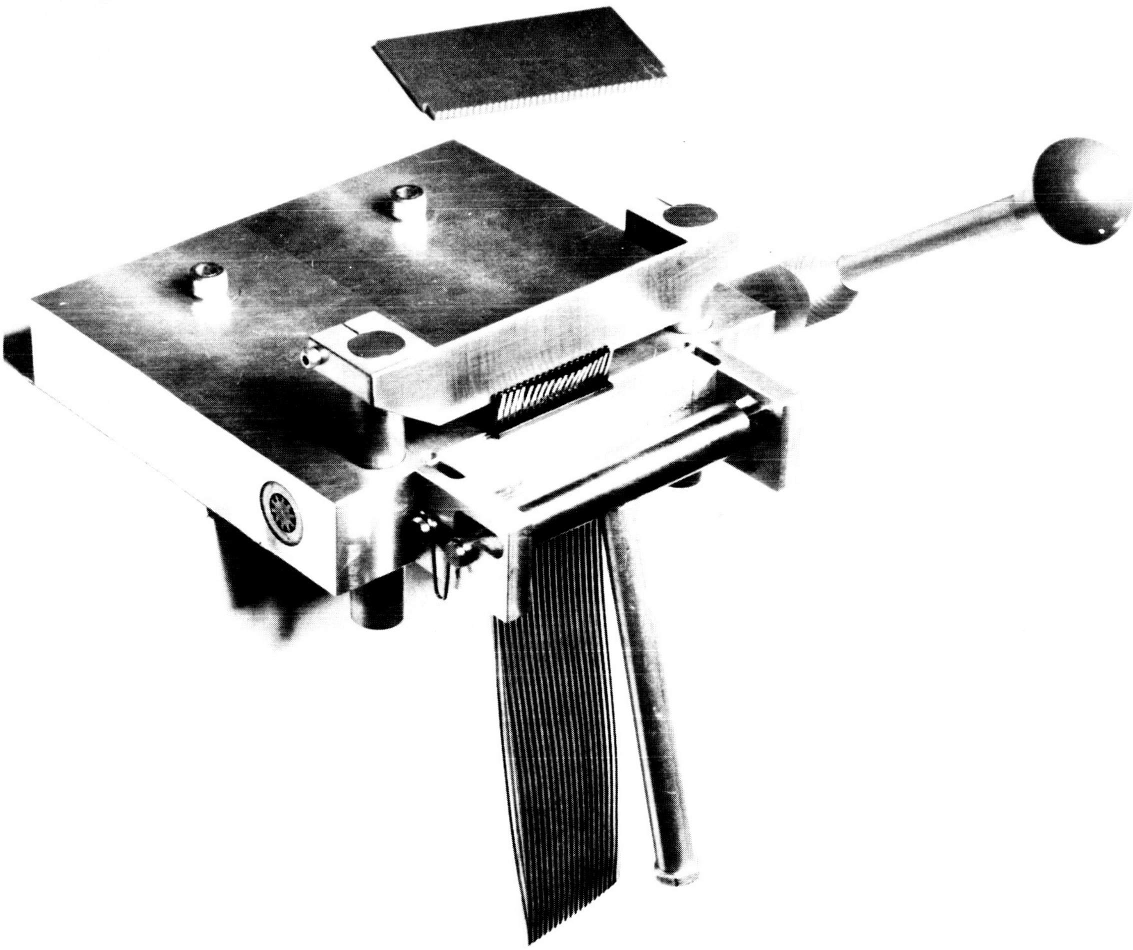


FIGURE 17. SEATING TOOL

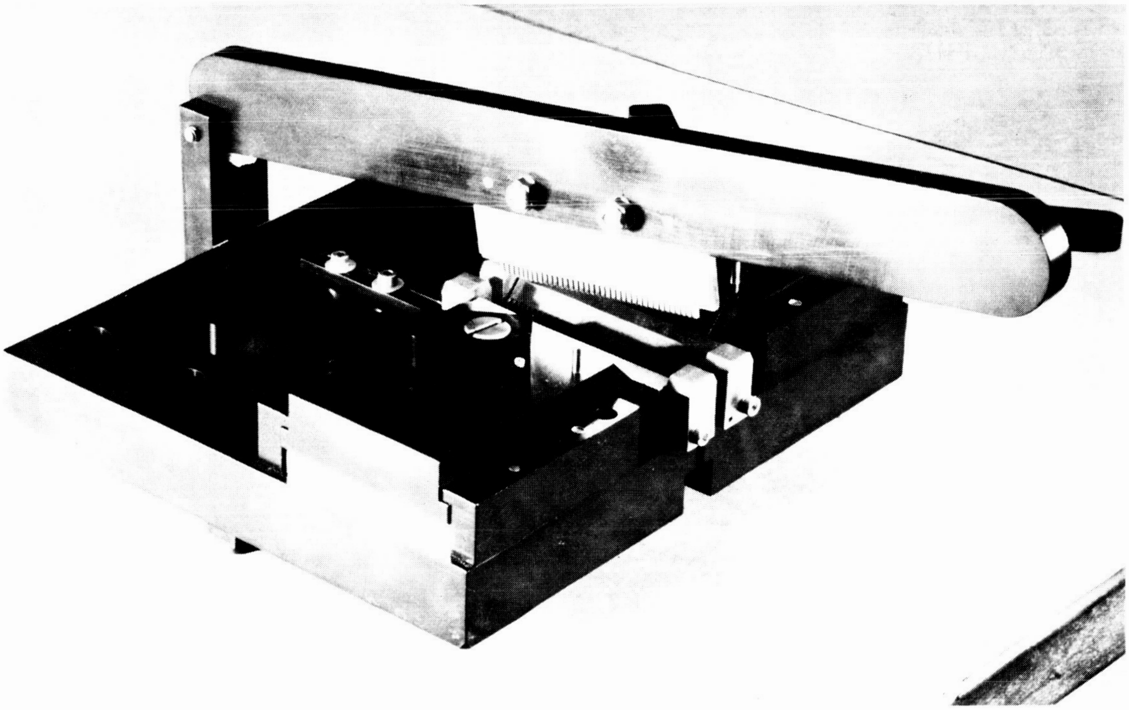


FIGURE 18. FOLDING TOOL

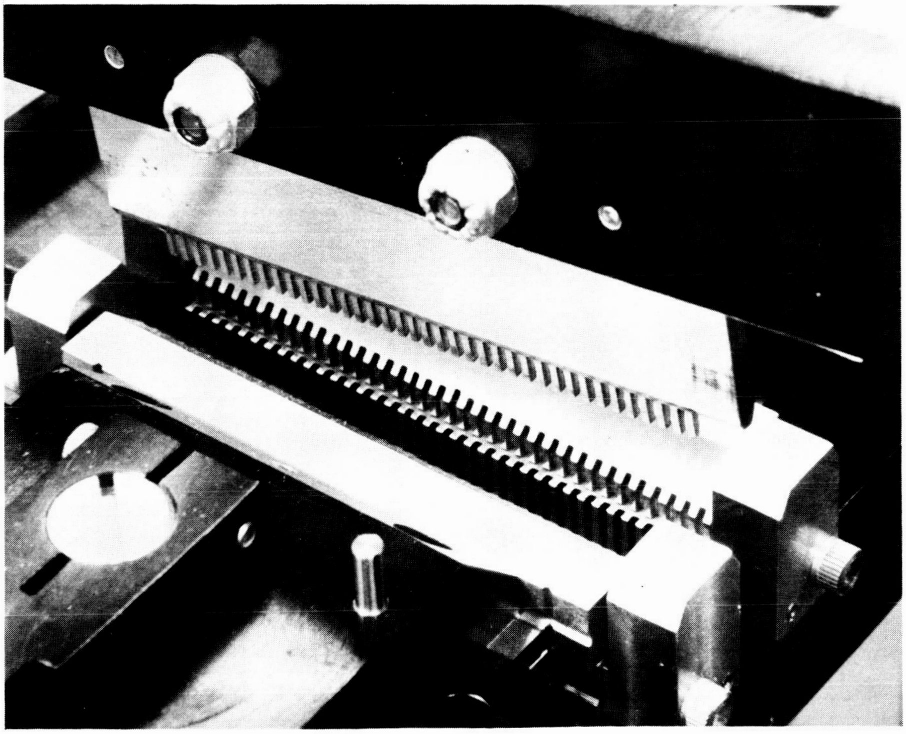


FIGURE 19. DETAILS OF FOLDING TOOL

A premolded plug termination (Fig. 20) is available for terminating cables in the field where molding equipment is at hand.

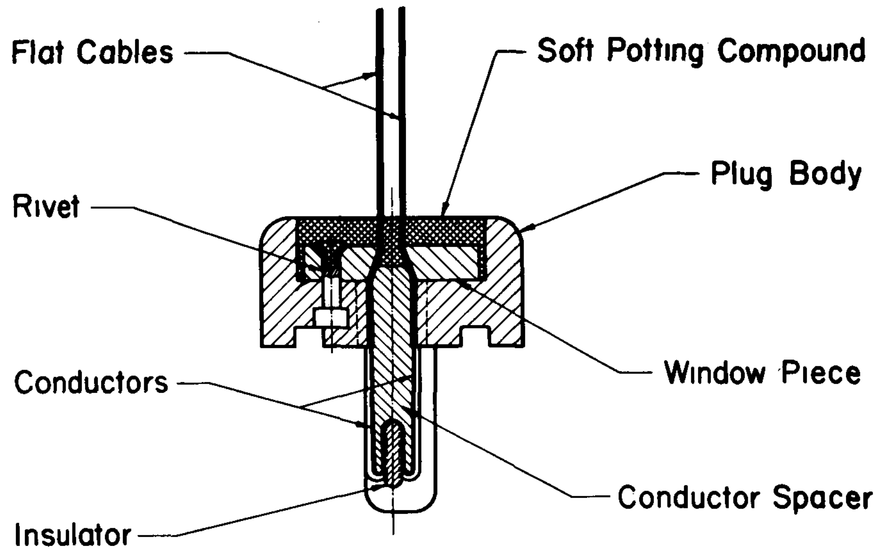


FIGURE 20. PREMOLDED PLUG TERMINATION

Figures 21 and 22 show a transition of a flat cable to round wires for termination in a round wire connector plug. Such an arrangement will be necessary when a round connector socket on a black box cannot be replaced by a flat cable socket because of lack of time or funds.

The flat conductors are folded over and into a premolded plastic carrier and the standard round wires are soldered to the flat conductors. The soldered or possibly crimped or welded junction is potted and firmly supported by a clamp connected to the plug body. The clamp in straight and 90-degree style can be rotated to allow any cable routing direction (Figs. 21 and 22).

RECEPTACLES

The receptacles are designed for reliability, simplicity, and light weight. They have heat-treated beryllium copper contact springs that are nickel and gold plated to match identically the conductor surface coating of the cable termination. The contact springs are contained in high-grade dielectric materials and sealed against moisture penetration. The spring containers are in a metal housing for environmental protection. A gasket serves as a seal between connector housing (shell) and the black box or bulkhead. The contact springs are carefully designed for making reliable low resistance contact. The contact points of the contact

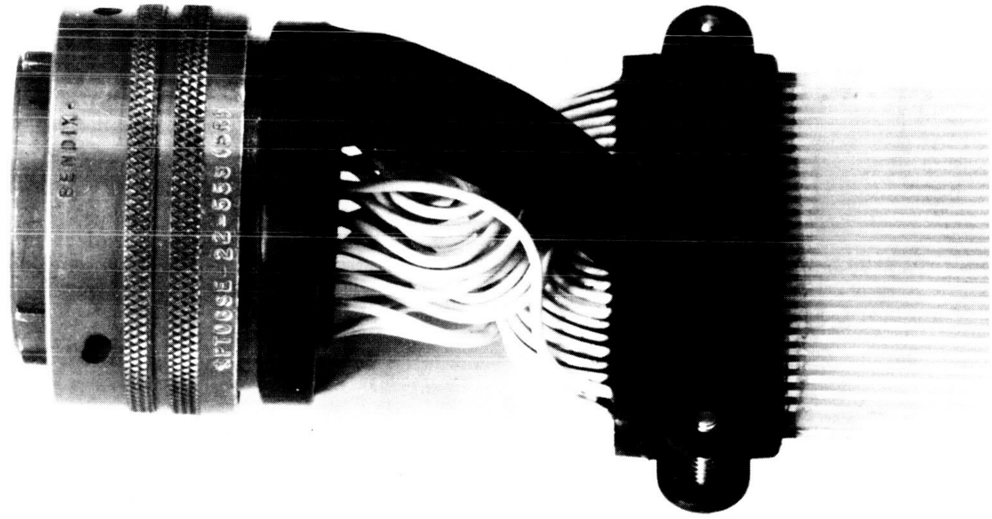
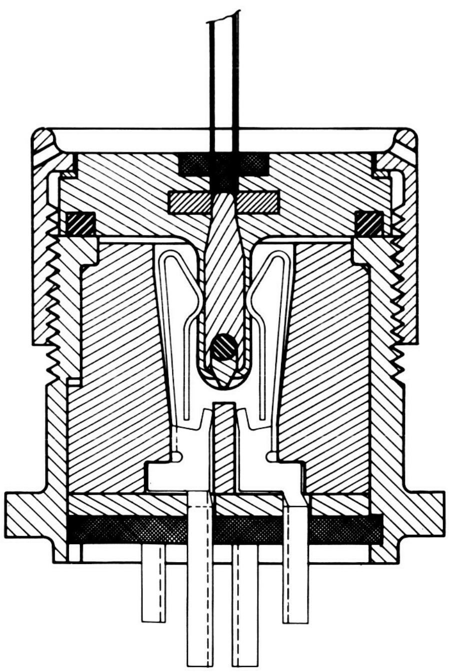


FIGURE 21. UNFINISHED ROUND WIRE CONNECTOR HALF (STRAIGHT)

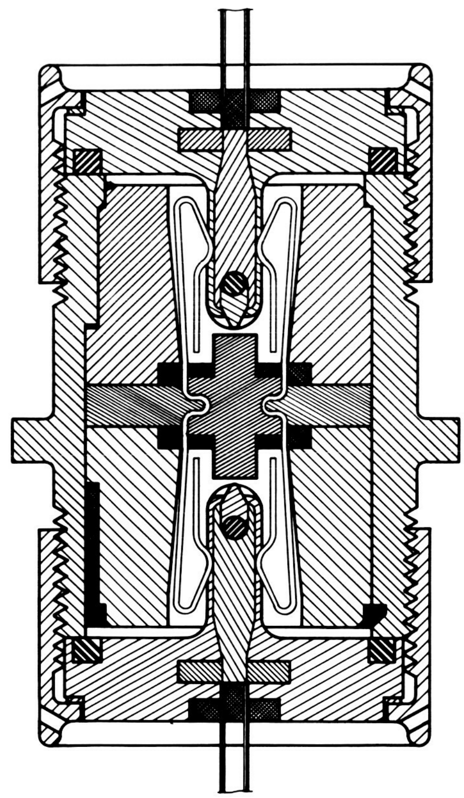
FIGURE 22. UNFINISHED ROUND WIRE CONNECTOR HALF (RIGHT ANGLE)

spring are spherically formed to reduce wear. The spring rate is designed for 1 mm deflection, resulting in approximately 100 gram force, and the spring is preloaded. The working deflection of the contact spring when the plug is inserted into the receptacle is about 0.6 mm (25 mils), which allows for fair tolerances in plug and receptacle manufacturing. Up to one milliohm contact resistance is considered acceptable.

Two types and configurations of receptacles have been developed and manufactured (Figs. 23 and 24). The first type is for receiving a flat conductor cable or a printed circuit board on the secondary side. The second receptacle has solder lugs for soldering stranded round wires. This second design was mainly produced for use with black boxes which have internal round wire harnesses. As mentioned previously, the flat cable receptacles can be used for power cables (cables with wide conductors) without changes. Only the busbars to join the solder lugs used for the power conductors need to be added. MSFC-SPEC-219A has been written for testing and qualifying flat conductor cable receptacles.



Plug-Solder Type



Plug -Plug Type

FIGURE 23. FEED-THROUGH AND SOLDER-WELL RECEPTACLES (CYLINDRICAL)

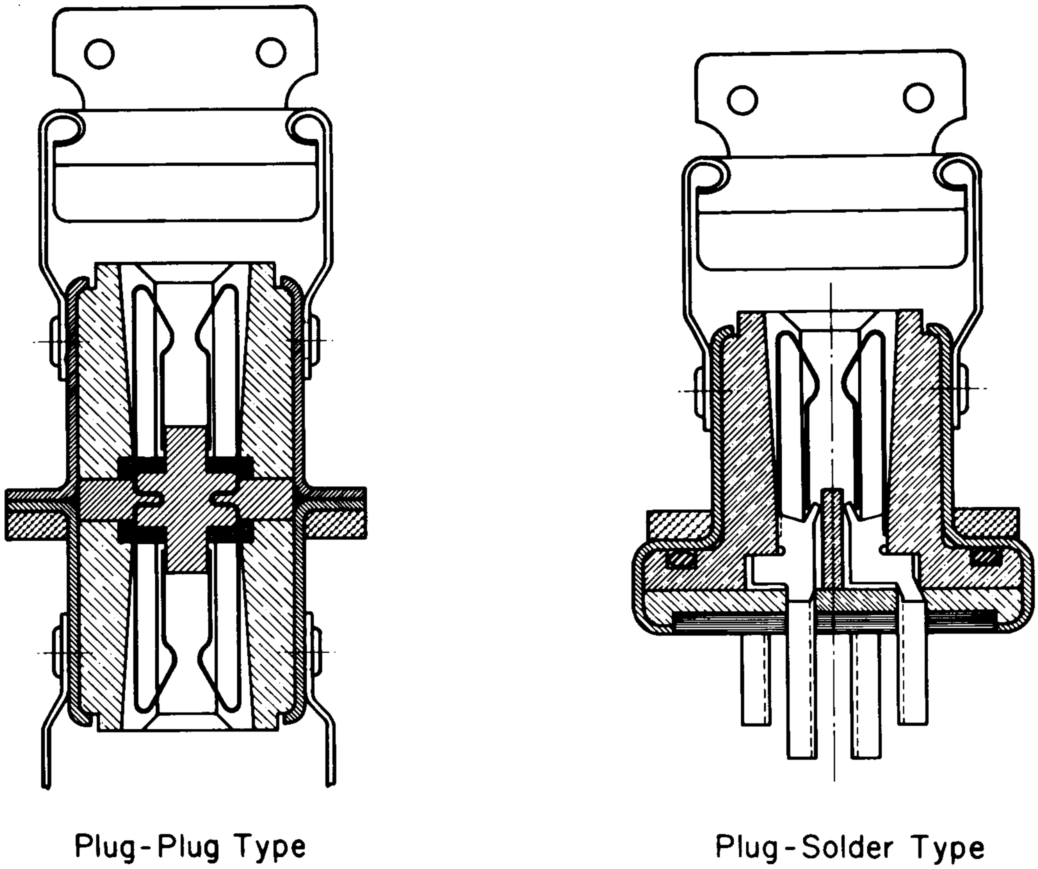


FIGURE 24. FEED-THROUGH AND SOLDER-WELL RECEPTACLES (RECTANGULAR)

FLAT CABLE ASSEMBLY AND DESIGN

To accomplish speed of production, to facilitate installations, and, when necessary, to make cable and diagram changes, flat cable designers should strive for simplicity rather than for a complex network that is consolidated into a single "harness." The word harness stems from the horse and buggy days and describes a fairly complicated system of interconnected strips of leather, lines, and ropes with hardware at the ends to connect to snaffle, pole, and single tree.

The round wire harness has some resemblance to such a horse harness, having also signal, control, and powerlines combined in one cable system. Straight cables with only one termination plug at each end should be used to harvest a maximum of inherent flat cable advantages. Complex interconnections can be accomplished in a single flat cable unit (Fig. 25), but it is cumbersome in making, storing, and handling, just as are the large round wire harnesses. The cable and black box designers should coordinate their efforts to simplify the cables and even increase the number of connectors when needed. Pin sequence coordination among the black box designers is mandatory to reduce the need for distributors. The coordination may be eased if every designer uses the same ground rules as much as feasible (e.g., pin 1 for dc minus, pin 2 for dc plus, the next pins for other power inputs, and then follow all other inputs; the last pins should be used for outputs).

A dummy pattern should be prepared from an inexpensive plastic tape, preferably Mylar 0.25 mm (10 mils) thick and as wide as the intended cable.

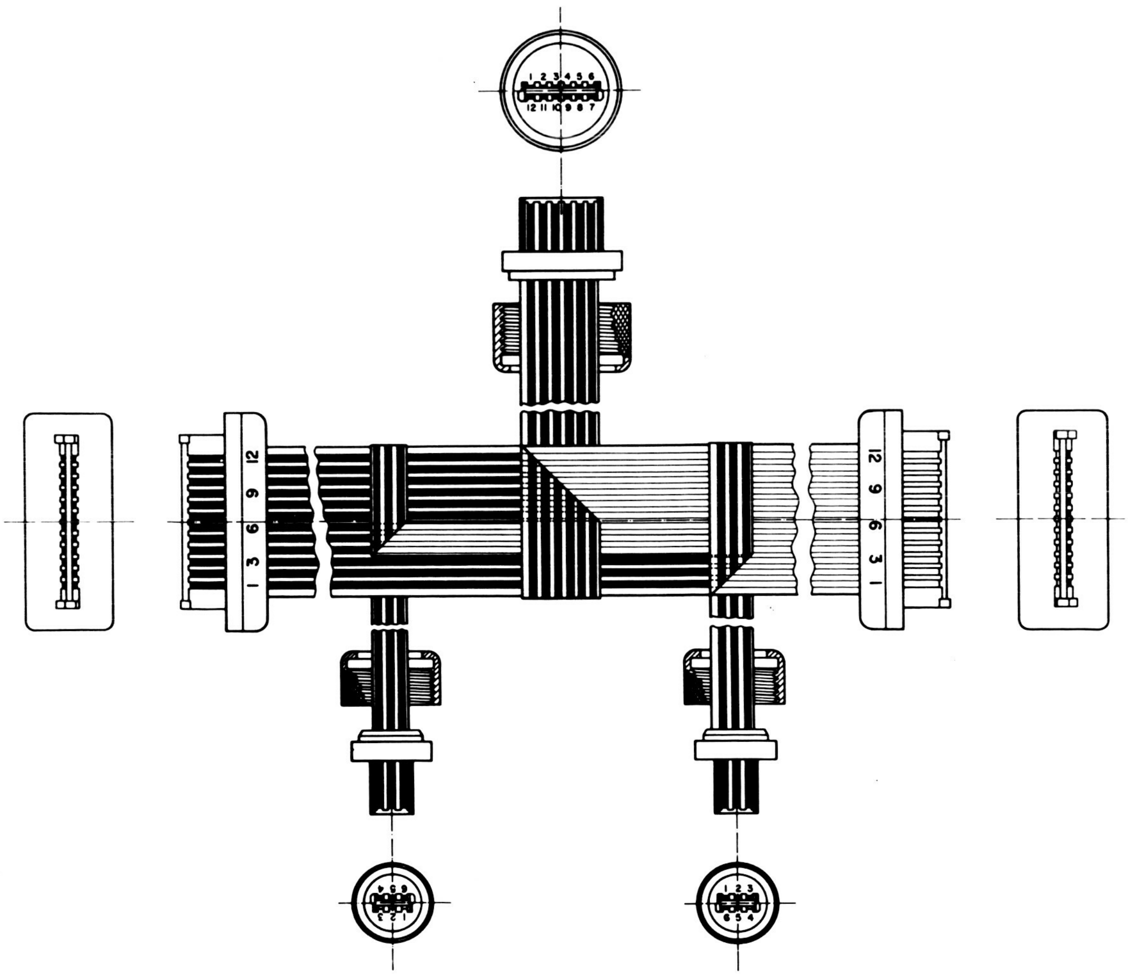


FIGURE 25. TYPICAL DESIGN OF ASSEMBLED CABLE

This dummy cable should be routed to the proper locations and folded where necessary; it should represent all dimensions of the final cable including the slack needed for handling the plug at each end. After all dummy cables have been completed, documentation can be made and the dummy cable can be used as an exact pattern.

In some instances, it may be practical to split a strip of cabling to form various branches. For this event, a splitting tool (Fig. 26) has been prepared.

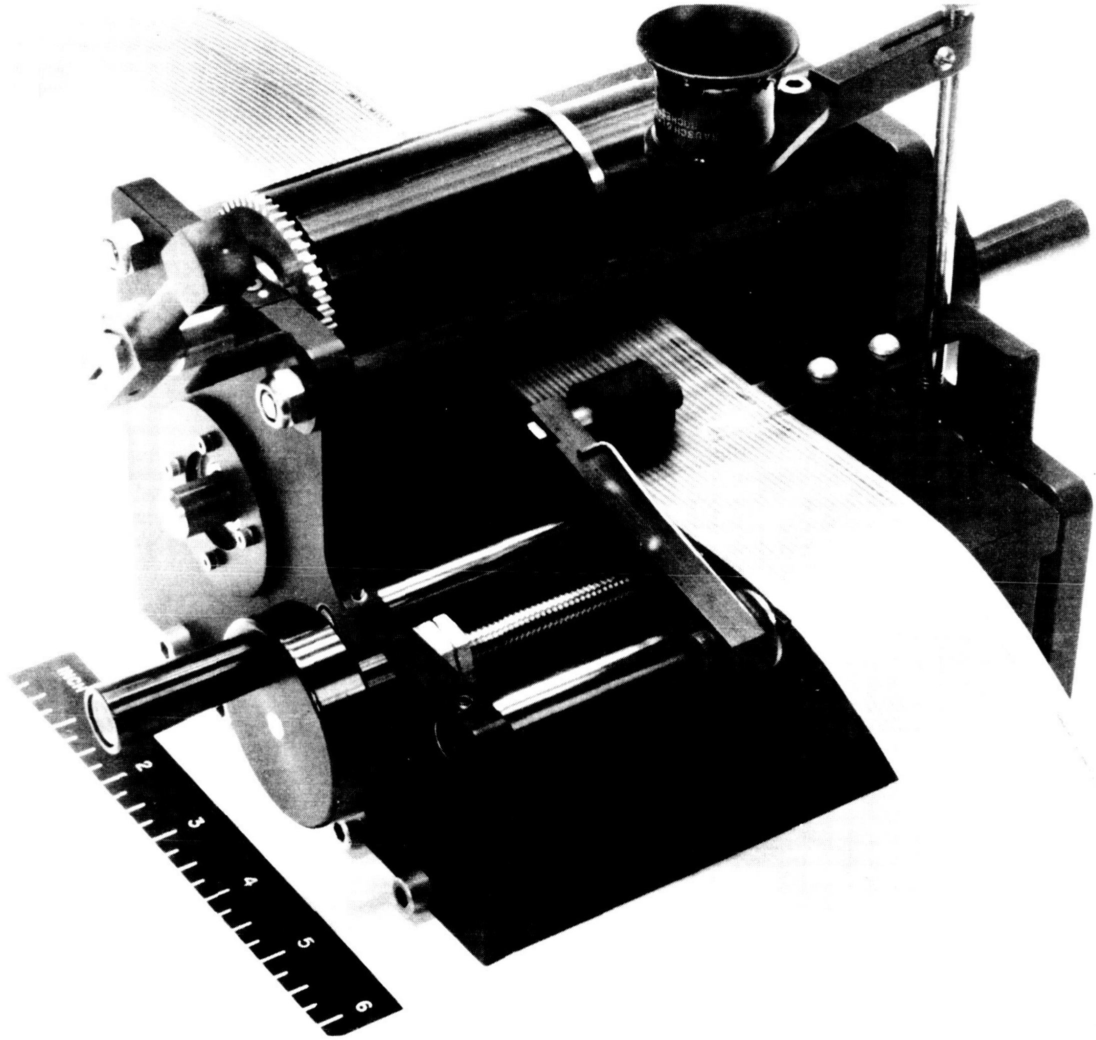


FIGURE 26. SPLITTING TOOL

Cable splitting is not a preferred practice, however, and is usually a last resort method caused by poor cable design planning at the beginning. A better way to obtain necessary branches is to terminate the required strips of cabling in a single plug. For example, Figure 27 shows a 75-mm (3-in.) strip opposed by three 25 mm (1 in.) strips that may be routed in any direction. A large variety

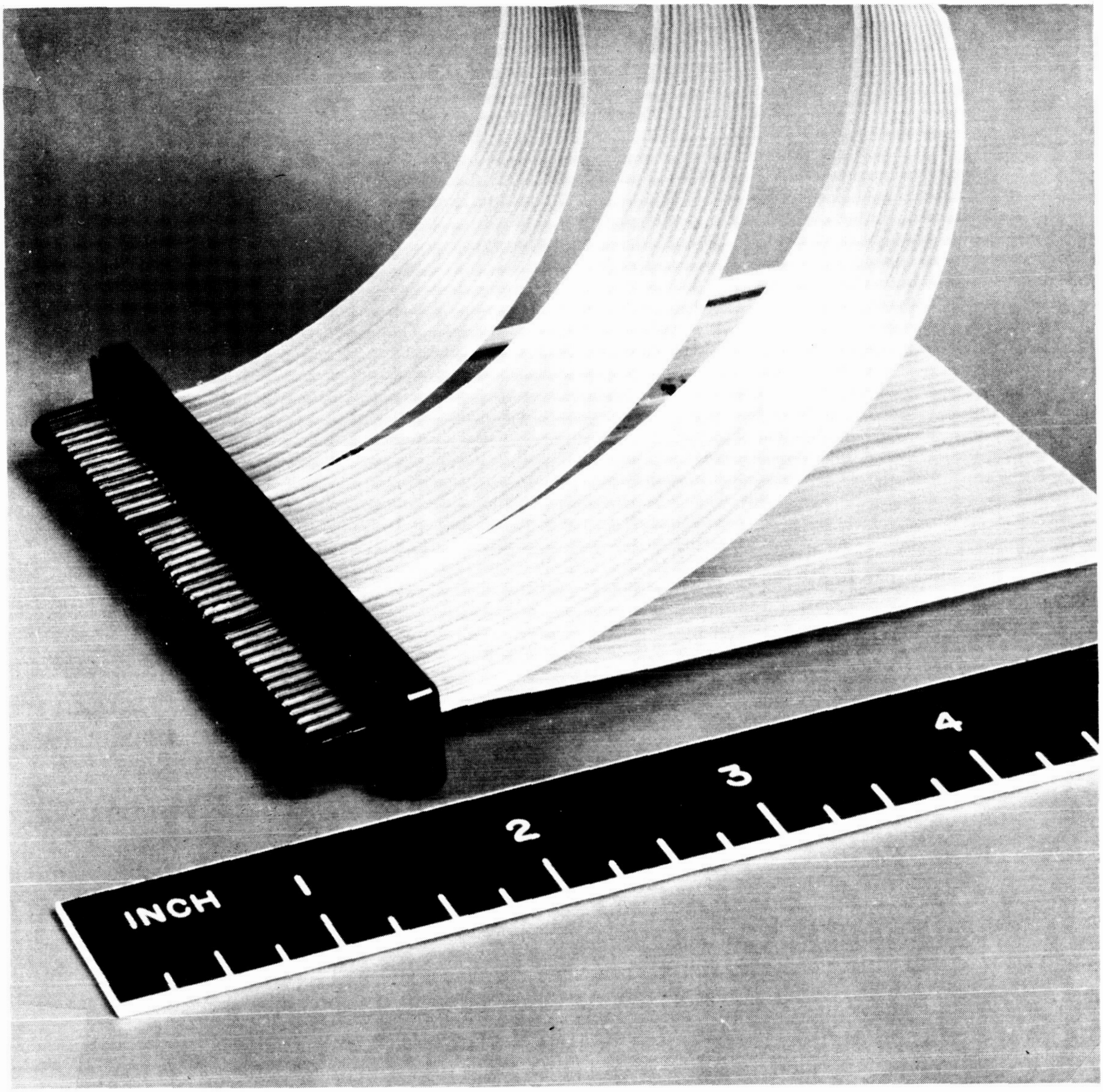


FIGURE 27. TYPICAL CABLE TERMINATING POSSIBILITIES

of combinations may be chosen. The most practical way to arrive at proper cable dimensions is to use an instrumentation mockup with exact locations of equipment to be interconnected. Building an instrumentation mockup is a very practical way to find the best location for instrument boxes. It should be made at an early phase of the design. The lead time for flat cable assemblies is very short compared with the lead time required for round cables. Therefore, the flat cable assembly need not be started before most of the wiring changes have been resolved. A wiring list indicating number and location of each wire termination should be prepared along with the dummy cables. After the dummy cables are properly placed and numbered, their plugs must also be labeled with numbers corresponding with the receptacles. Before removing the dummys from the mockup, appropriate markings on substrate for routing the final cables are recommended. The dummy cables serve as path finders; having the size and configuration of the final cables, they can be used to produce documentation and will be the patterns to make the actual cables. To calculate the cable dimensions and folds from a study at the drawing board rather than using a mockup has resulted in costly mistakes and there is little hope of overcoming the pitfalls of the paper study. A rough paper study may be used only for determining the amount and type of cabling needed for the project.

CIRCUIT CHANGE - METHODS AND HARDWARE

The question may arise, How can wiring changes be made in a flat cable system? The cable itself is not a change gear; therefore, special means, such as wire change plugs and small distributors, have been designed for this purpose. Figure 28 shows a diagram of a premolded plug which allows complete change of pin function as may be needed. The flat cable is slitted to individual insulated

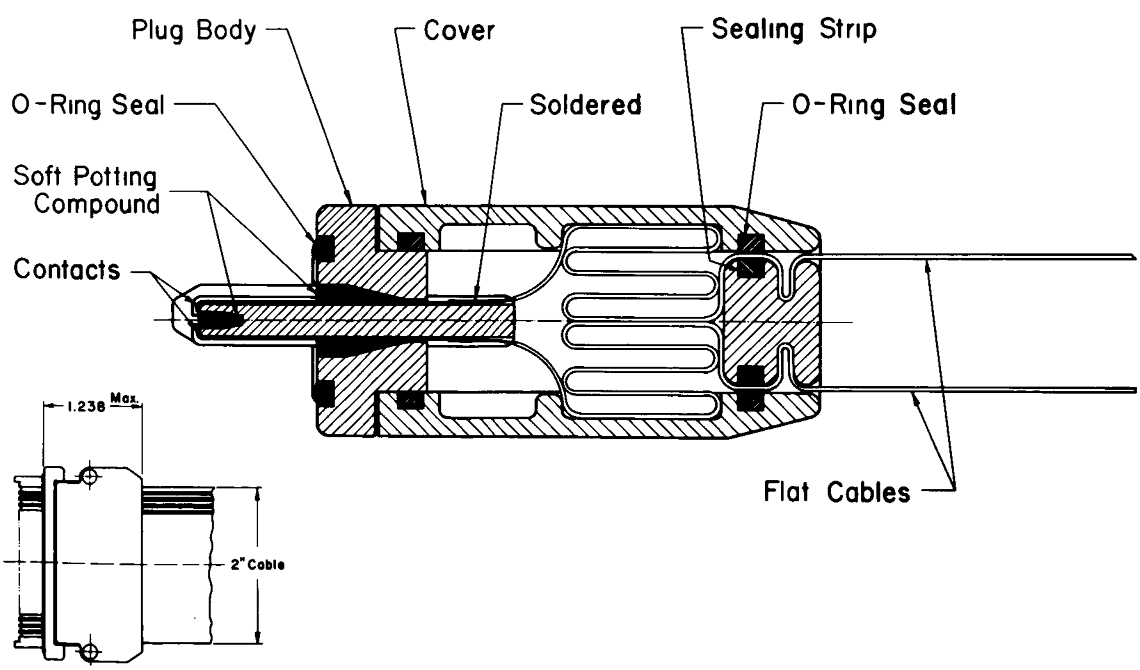


FIGURE 28. PREMOLDED CONDUCTOR CHANGE PLUG

conductors and folded back and forth for sufficient length to reach any contact point of the plug. The connections are made by soldering; welding would also be possible but it restricts the number of rechanges per contact.

Another means of changing the wiring diagram is the introduction of a small distributor box. The distributor box should be placed near a black box and in line with the cable which may require changes. The flat distributor box (Figs. 29 and 30) consists of a PC board terminated by two flat cable receptacles. Any wiring change can be made on the PC board without any physical change to the flat cable. The second type of flat cable distribution box (Fig. 31) uses a jumper wire for each cable conductor. These jumpers can be changed to suit the need, either by soldering or using the AMP, Inc., termi-point approach. A distributor for two 50 mm (2 in.) cables, having 50 incoming and 50 outgoing conductors, weighs about 200 grams, which is 4 grams per conductor.

In case only minor changes are needed, the conductors can be routed within the standard molded plug before molding.

FLAT CABLE INSTALLATION

After all individual cables have been prepared to the dimensions of the patterns and terminated by plugs with the properly oriented polarization keys as indicated on the Mylar dummy cable strips, the cable installation can start.

In earlier studies of flat cable installations, various adhesives were used to fasten cables to supporting structures. Now, after more experience has been gained, clamps are preferred for internal mounting as shown in the Saturn S-IVB stage aft skirt study which is discussed in the following section of this report. Flat cables installed in a liquid container and subjected to violent sloshing during flight would have to be fastened on the entire length with adhesive and clamped in critical places. Outside mounting on flight vehicles should also be done with adhesives to eliminate the clamps and their installation effort and to reduce the aerodynamic drag. Qualified adhesives are listed in Table III. The bond strength increases considerably with aging. Extensive testing with EC 1099 used for bonding 3 1/2 m (12 ft) Mylar and Kapton cables to a large liquid oxygen tank proved the ability of the adhesives to stand the many and severe temperature changes of 113 to 303°K(-160 to 30° C) over several months and the contractions and expansions of the tank without delamination. A weathering test (both cable types cemented to an aluminum panel) over three years of exposure to rain, sunshine, heat, and cold weather showed no defect of the bonds.

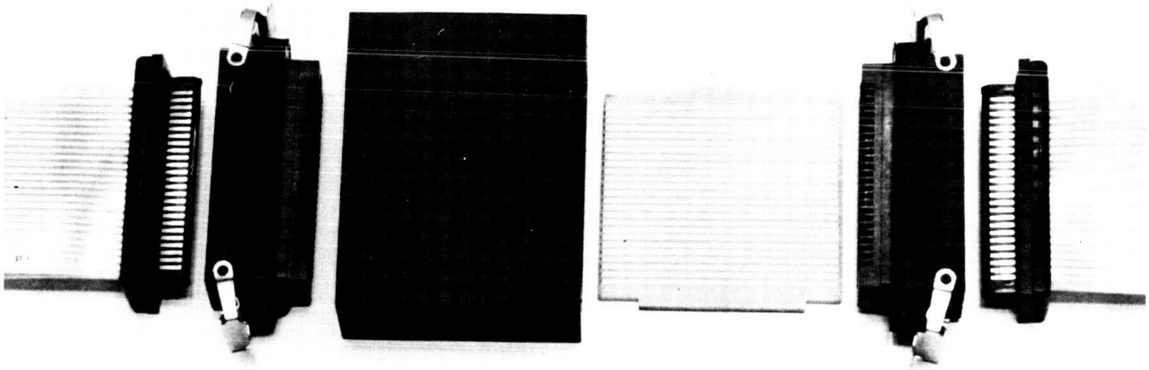


FIGURE 29. UNASSEMBLED CONDUCTOR CHANGE DEVICE (PC BOARD)

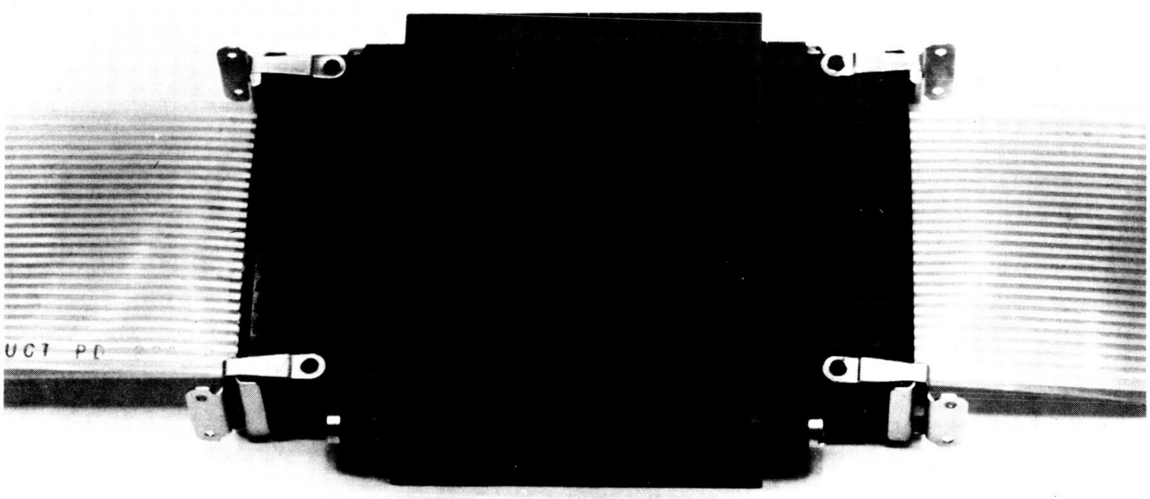


FIGURE 30. ASSEMBLED CONDUCTOR CHANGE DEVICE (PC BOARD)

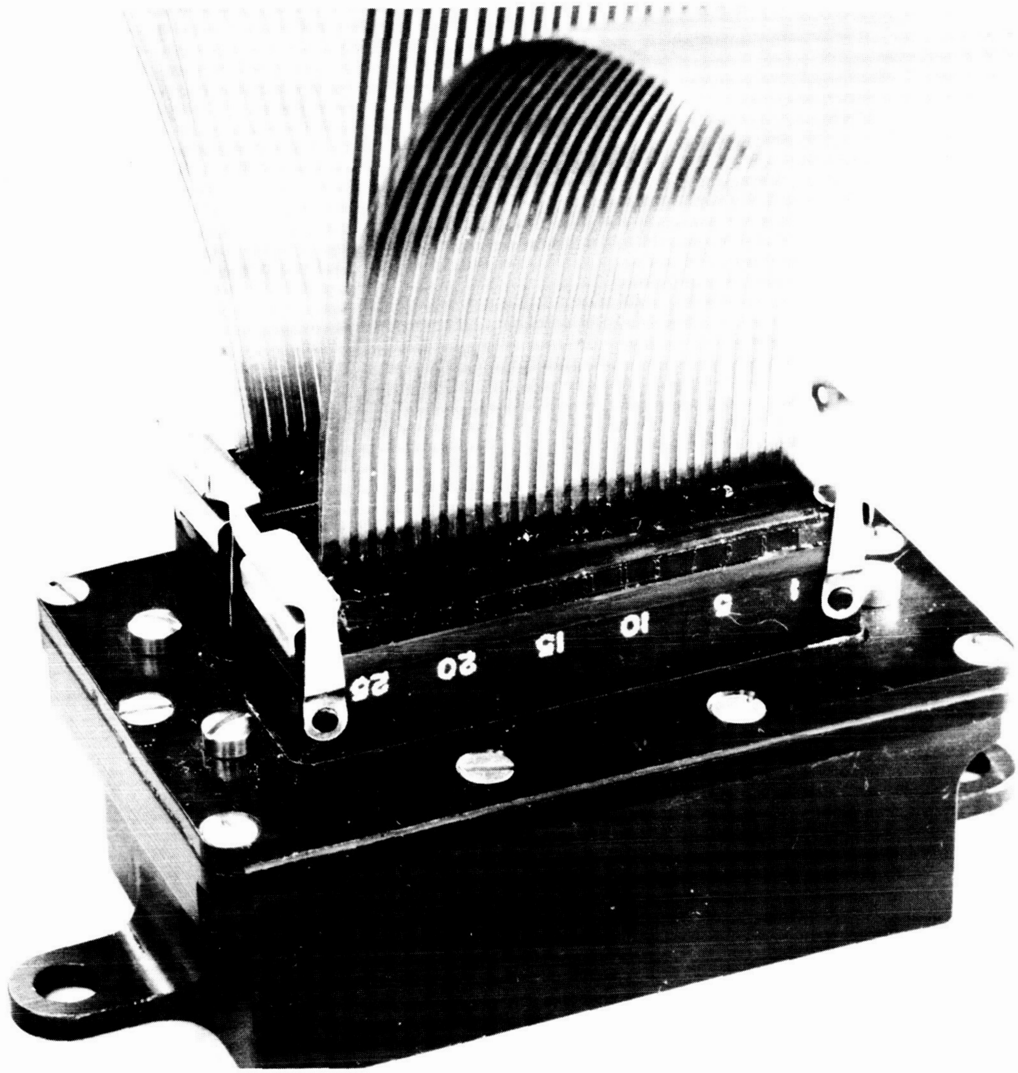


FIGURE 31. CONDUCTOR SEQUENCE CHANGE BOX

Cables are generally stacked for clamp mounting but should not be stacked for adhesive mounting unless there is no chance for the cables to be torn loose by sloshing or aerodynamic forces. Stacking or separation of cables may also be influenced by electromagnetic interference considerations, as discussed on page 8. Electromagnetic interference may require protection for the circuits by shielding or physical separation; both means are very effective. Detailed information can be found in Reference 1. In a few months, results of more recent studies under contract to Hughes Aircraft, Douglas Missile and Space Laboratory, and Picatinny Arsenal will be published.

TABLE III. ADHESIVES FOR FLAT CABLE INSTALLATION

Designation	EC 1099	Silastic 140	5277
Mfg Source	3M	Dow Corning	Fasson
Type	Nitrophenolic	Silicone	Polyester
Condition	Liquid	Paste	Film
Application	Brush	Trowel	Hand
Mat Bonded	Mylar, Kapton	Mylar	Mylar, Kapton
Temp Range	113 to 393° K (-160 to 120° C)	113 to 373° K (-160 to 100° C)	248 to 373° K (-25 to 100° C)
Cure Temp	Room Temp	Room Temp	Room Temp
Cure Time	24 hours	24 hours	24 hours
Bond Strength	2.7 kg/cm (15 lb/in.)	2.2 kg/cm (12 lb/in.)	1.8 kg/cm (10 lb/in.)

The actual cable installation is a very small effort if all engineering and cable preparations have been done carefully. Clamps of various types, found to be practical, are as follows. First, there is a simple hook for use in temporary and dummy wiring to hold the cables in place and to allow additions or removal of cables without losing tne position of the others. The second type is a more permanent omega-shaped aluminum clamp (Fig. 32). It has a foam rubber cushion which holds up to 10 cables of various widths. The clamp is fastened to the supporting structure by two plastic snap-in buttons, which can be extracted for cable addition or removal. The third fastener (Fig. 33) is made of Velcro-Nylon tape, which is fastened to the supporting structure by snap-on buttons, rivets, or screws and folds over the prepared cables. Where the Velcro tape clamp is to be applied, the cables are tied together with another Velcro-Nylon tape, which is secured by pressure sensitive adhesive. Both clamps have passed extensive vibration testing.

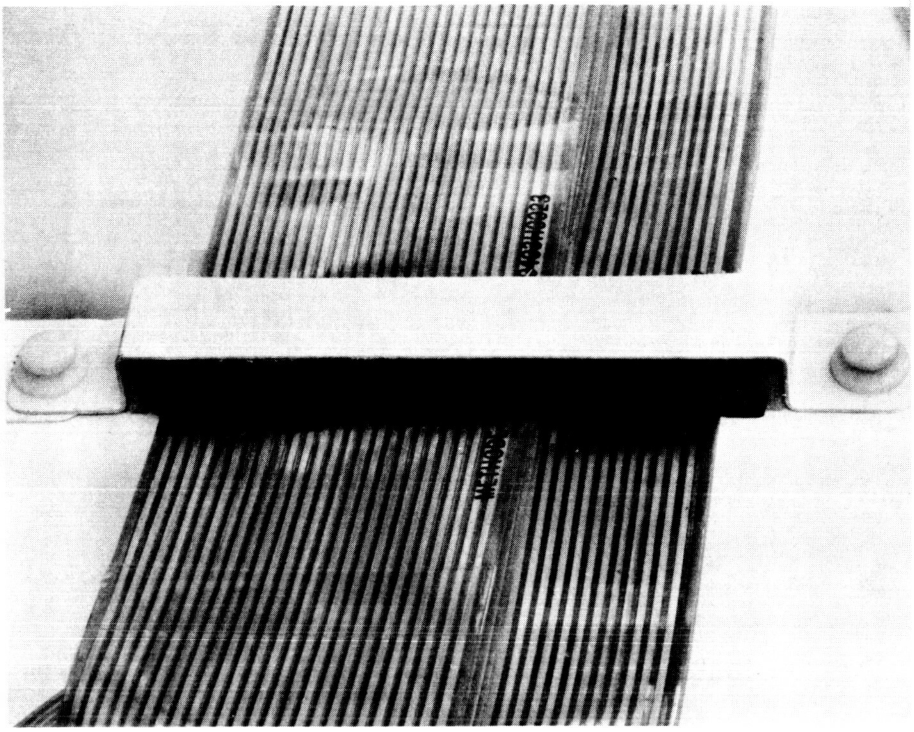


FIGURE 32. FLAT CABLE INSTALLATION CLAMP (ALUMINUM)

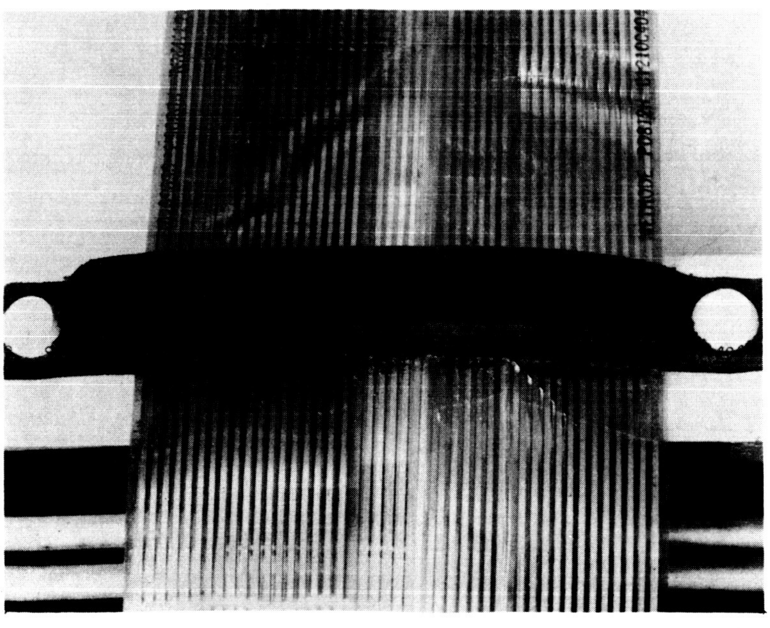


FIGURE 33. FLAT CABLE INSTALLATION CLAMP (VELCRO-NYLON TAPE)

FLAT CABLE APPLICATION STUDY

To gain experience and to arrive at hard figures as to the pros and cons of the flat cable system, NASA-MSFC let a contract to Douglas Missile and Space Division at Huntington Beach, California. The contract called for an actual engineering and installation study of the aft skirt areas of the Saturn S-IVB stage. The duration of the contract was eight months and the total amount of flat cable installed was 15 km (50 000 conductor ft). The ground rule was to change all round cables having wire AWG No. 19 and smaller to flat conductor cables. Coaxial cables were excluded. The assumption was made that all receptacles at the instrument boxes would be of the flat cable type and that 50 percent of the presently shielded cables would be shielded flat cables. The conversion limit at AWG No. 19 was arbitrarily set; in later studies, it was extended to heavier gages. The flat versus round cable installation is shown in Figure 34. The results of this study are given in References 2 through 5.

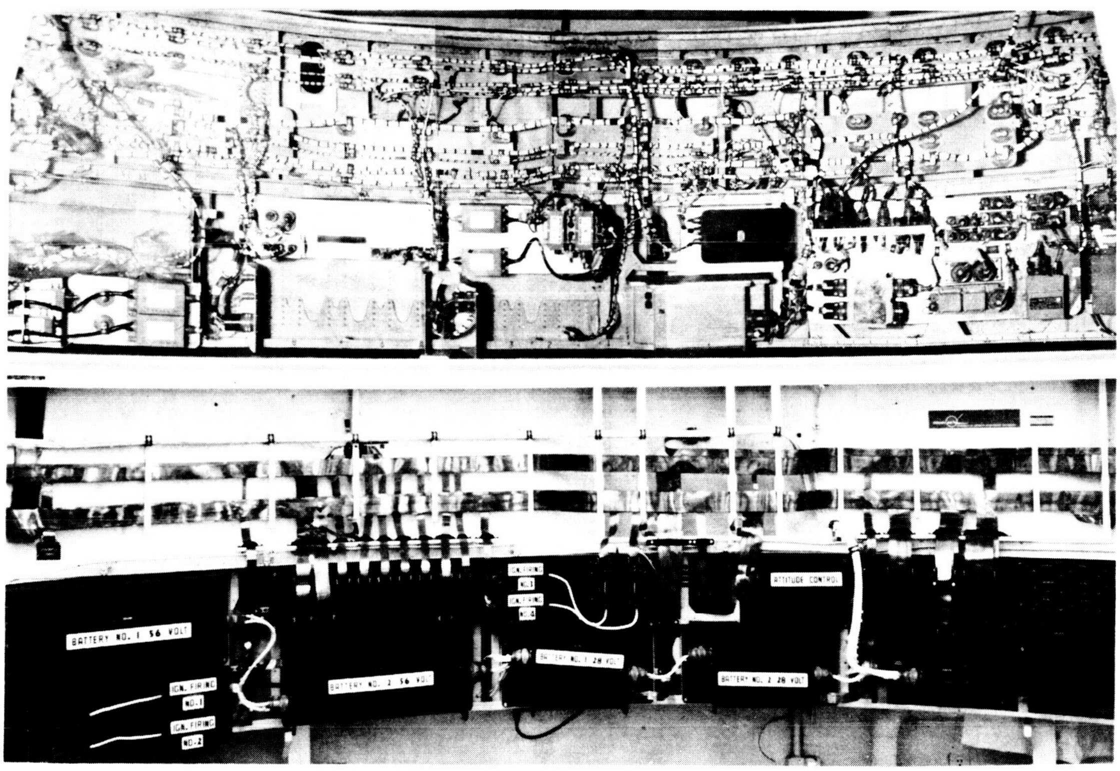


FIGURE 34. FLAT VERSUS ROUND CABLE INSTALLATION (S-IVB AFT SKIRT, BATTERY AREA)

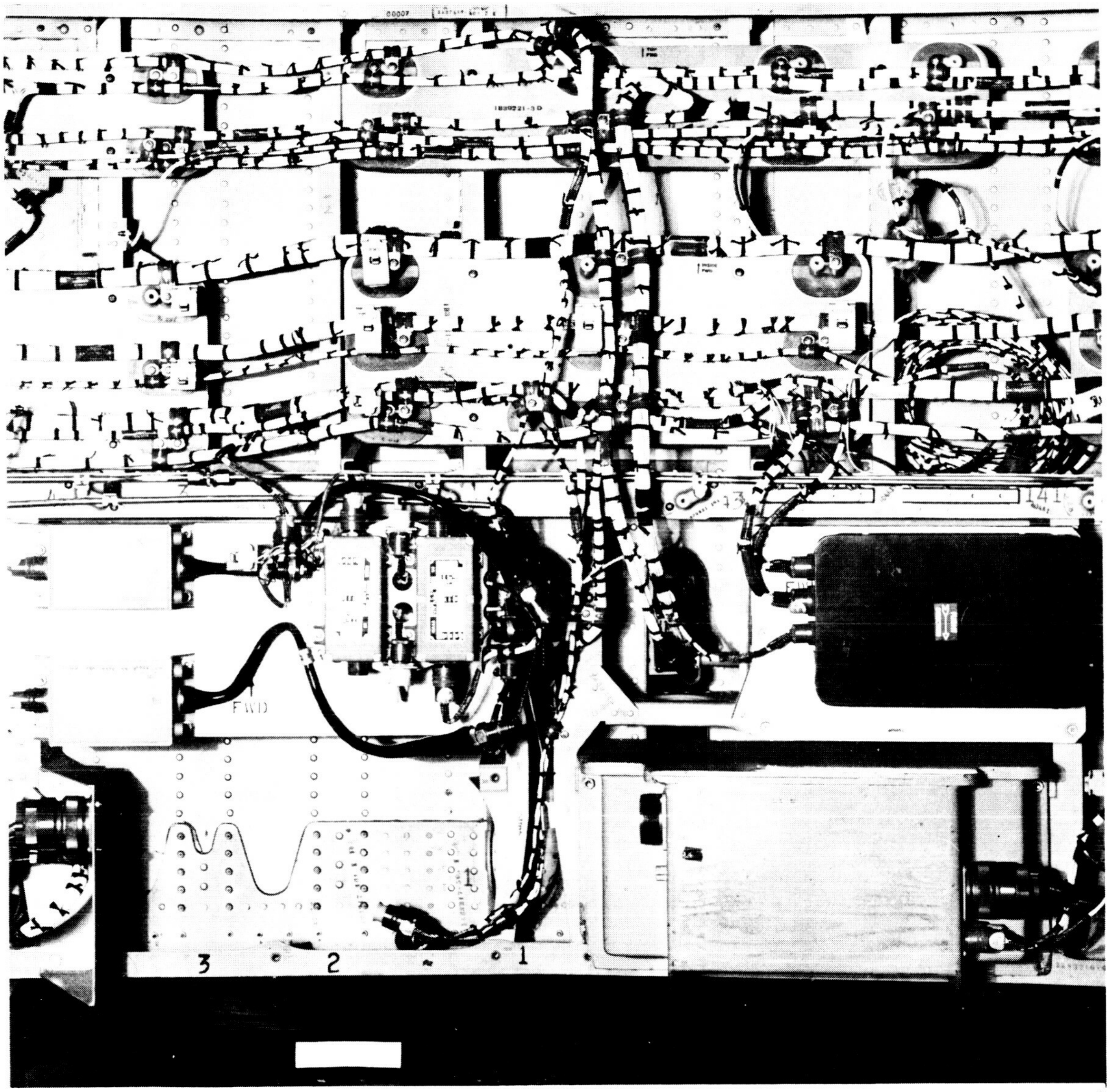


FIGURE 35 . ROUND CABLE INTERCONNECTION OF S-IVB COMPONENTS

Note that mounting plates and fasteners used for the round wire cables were radically simplified in design and weight because the flat cables are much lighter and less sensitive to vibrations. In other cases, where the round wire mounting hardware is simple and the conversion of round wire to flat cable encompasses much heavier gages, the weight saving may be only 50 percent which is still a worthwhile factor.

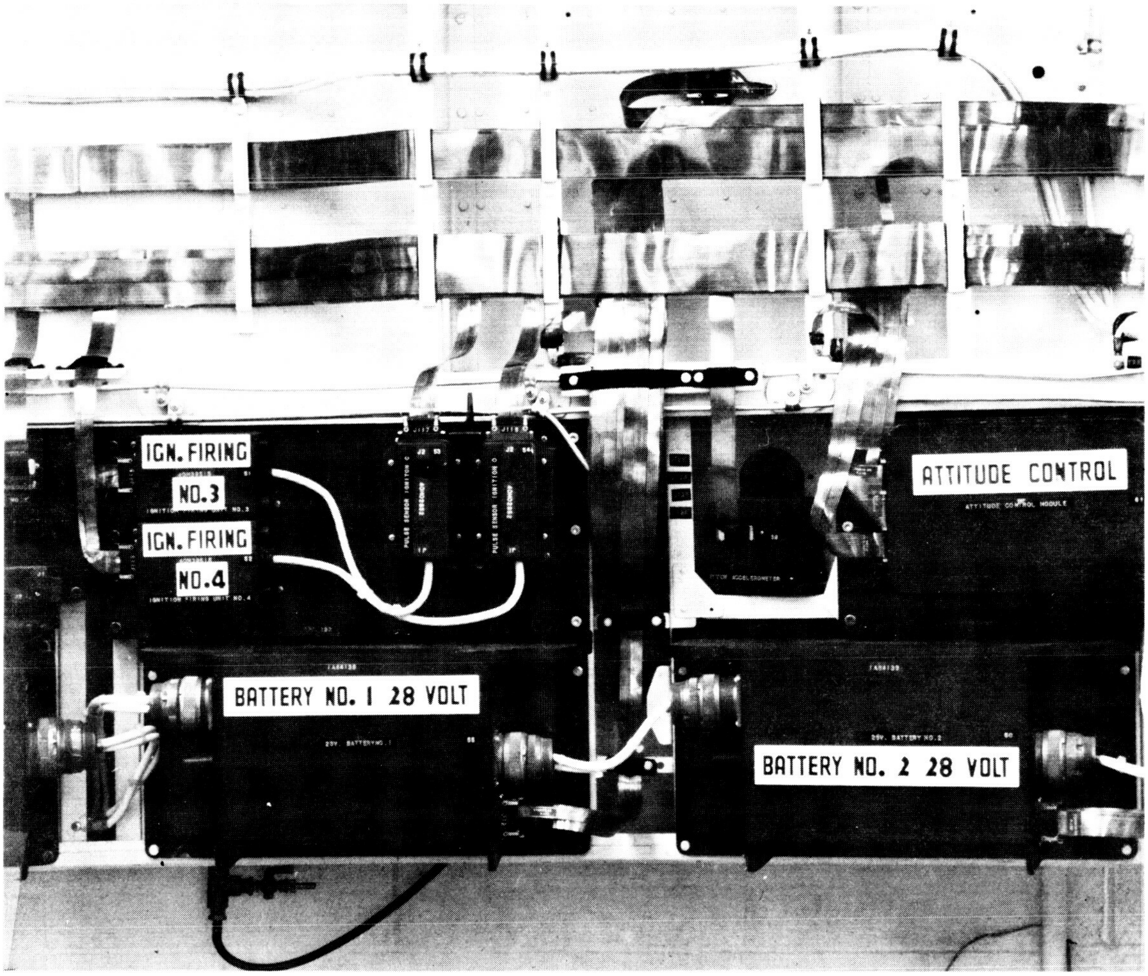


FIGURE 36. FLAT CABLE INTERCONNECTION OF S-IVB COMPONENTS

Figures 35 and 36 provide details of specific components to illustrate the comparative neatness of routing and installation. The main results are as follows.

Weight Saving

	Round Cable kg(lb)	Flat Cable kg (lb)	Saving kg (lb)	%
Mounting hardware	185 (413)	21 (46)	16 (367)	89
Harness weight	460 (1010)	135 (297)	325 (713)	70
Total	645 (1423)	156 (343)	489 (1080)	76

Time Saving

Cable assembly, termination, and installation including fastener manufacturing and installation were compared. The figures are based on a log of 100 installations and the figures of the 90th item in the learning curve are given below:

	Round Cable Hours	Flat Cable Hours	Saving Hours	Saving %
Cable Assembly	2125	400	1725	80
Installation	1113	364	749	67
Total	3238	764	2474	76

Material Cost Saving

The costs of the materials needed to build and install a complete wiring system in round and flat conductors are as follows:

	Round Wire $	Flat Cable $	Saving $	Saving %
Wire	1430	5195	-3765	-260
Plugs	4730	700	+4030	+ 85
Fasteners	3207	404	+2803	+ 88
Total	9367	6299	+3068	+ 33

The saving of 33 percent is very moderate because of the higher flat cable cost. If flat cables cost the same as round wires, then the saving would go up to 70 percent. The flat cable will probably cost even less than round wires when sales volumes warrant the investment of higher quantity cable production equipment. The cost figures of the connector receptacles are not included. The flat cable receptacle is less expensive than the one for round wires; therefore, the cost of the flat cable system will be still lower.

RELIABILITY ASPECTS

The analytical study of quality and dependability of an electrical cable system shows current leakage, conductor breakage, and junction failure as the major points of concern. The flat cables under consideration for use at NASA have the best insulation materials (Mylar and Kapton) ever produced. Their mechanical and electrical strength combined with the geometry of the conductors makes flat cables far superior in comparison with round wire cables of comparable weight and cost. The simplicity of the flat cable termination, mainly the use of the cable conductor as contact member of the plug, is the most striking advantage over any other design for a separable connector. Furthermore, the carefully designed contact spring of the receptacle, having a spherical contact of controlled radius, spring rate, spring deflection, and contact force, is a built-in warranty for perfect and lasting performance. Considering all these facts, it can be concluded that the application of all available connector experience and sound engineering principles has produced the new flat cable and connector system with excellent results as reflected in many tests.

CONCLUSIONS

The present production technology indicates the feasibility of producing flat cables of high quality in large quantities and at reasonable cost.

Extensive development and manufacturing efforts have investigated several approaches to find the most suitable cable termination design. Two connector types in seven sizes, each ranging from 6 to 75 mm (0.25 to 3 in.) cable width, are in production tooling. Advanced production samples have passed preliminary testing. The problem of how to handle last minute wiring changes has been solved by the development of suitable hardware and procedures. The flat cable installation study of the Saturn S-IVB stage conducted by Douglas under NASA contract has proved the feasibility of the flat cable system and has shown great savings in weight, time, and material cost. The analytical reliability study promises substantial advantages over the round wire cable systems.

The interest in flat cables is increasing rapidly because of the accomplished technological advancements and the simplicity of the system. NASA-MSFC will apply flat conductor cables in all new programs to the practical maximum extent. It is hoped that other government organizations and the entire industry will begin to use flat cables on a larger scale and continue to make their contributions towards further development and improvement.

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FLAT CONDUCTOR CABLE MANUFACTURE AND INSTALLATION TECHNIQUES

By Wilhelm Angele

The information in this report has been reviewed for security classification. Review of any information concerning Department of Defense or Atomic Energy Commission programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.

This report has also been reviewed and approved for technical accuracy.

W. Haeussermann

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Director, Astrionics Laboratory